



The New Generation Pozzolan for Superior Concrete

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SYNOPSIS

“Super-Pozz®” is a unique, ultra-fine and highly reactive pozzolan, which can supply all round benefits to various cementitious systems. This paper presents results of an investigation carried out on Super-Pozz®, at various replacement levels in concrete, and the effect it has on workability, water requirement, admixture requirement, strength and durability.

The work also highlights the morphological characteristics of Super-Pozz® and illustrates how these can be utilized to produce superior concrete. Results obtained confirm that properly designed mixes exhibit properties similar to formulations containing silica fume.

INTRODUCTION

For a given concrete consistency, a reduction in water requirement is known to lead to an overall improvement in many engineering properties of the hardened concrete.

In high performance concrete applications, silica fume is generally proposed as the appropriate cement extender where high strengths, low permeability are the prime requirements. Though silica fume is known to improve durability, its addition in concrete is often negated by the increase water and/or admixture dosage required to improve the workability and handling properties of the fresh concrete.

With the development of a highly efficient pozzolan called Super-Pozz®, indications are that appropriately designed mixes can at least be as durable as similar mixes containing silica fume. Generally when silica fume is used in concrete, due to its extreme fineness and high surface area, the amount of water required to obtain a given slump is increased. To offset this increase in water requirement, it is virtually standard practice to incorporate a high-range water-reducing admixture. With Super-Pozz, the situation is changed. Due to its unique chemistry and ultra-fine particle size, Super-Pozz provides a reduced water demand for a given workability; even up to 20% replacement level. Due to its ability to reduce water and/or admixture, Super-Pozz can either be used as a high range water reducer to improve compressive strengths or as a super workability aid to improve flow.

CHARACTERISTICS AND PROPERTIES

As can be seen in the chemical composition and physical characteristics listed in Table 1 and Table 2, Super-Pozz is an extremely fine, light colored powder composed primarily of amorphous calcium-silicates and aluminates. From its chemical analysis, Super-Pozz will meet the Class F fly ash requirement of BS 3892, but physically the product is unique with regards to its particle size distribution. The D_{99} value is 25 micron, the particle size below which 99% of the particles are to be found. Figure 1, illustrates the comparative particle size distribution analysis.

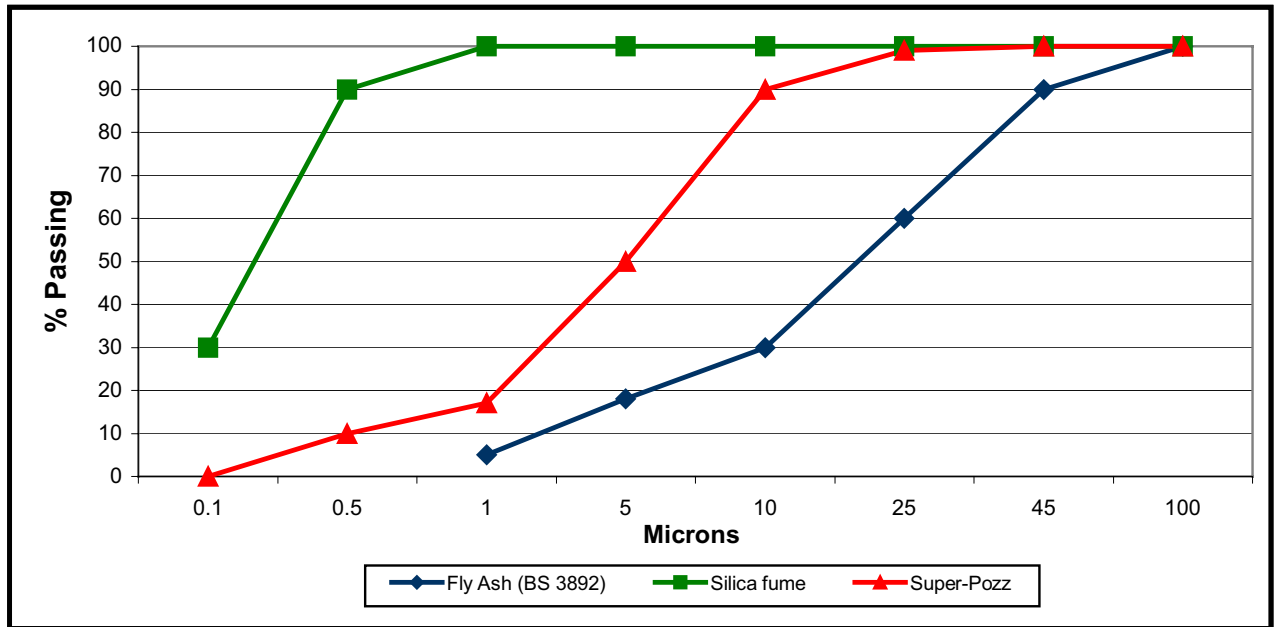
Table 1:
Typical chemical composition

Chemical Analysis	Mass %
SiO ₂	53.5
Al ₂ O ₃	34.3
CaO	4.4
Fe ₂ O ₃	3.6
K ₂ O	0.8
MgO	1.0
Actual Carbon Content	< 0.3
LOI @ 950°C	< 1.0

Table 2:
Typical physical characteristics

Physical Analysis	Mass %
Relative Density	2.20
Surface Area (cm ² /g)	13000
PH	11 – 12
Colour	Light grey
Particle Shape	Spherical
Particle Size, D ₉₀	11 μm
D ₉₉	25 μm
Mean Particle Size	4.0 μm

Figure 1: Particle Size Distribution



CONCRETE QUALITY AND MIX DESIGN

The quality and impermeability of high-performance concrete are, inter alia, determined by the amount of water utilized in the mix design i.e. the water/binder ratio. High range water reducers (HRWR) are extensively used to ensure placement with low water contents. Ultra-fine pozzolanic materials such as silica fume, is often utilized in HPC. The presence of the extremely fine particles decreases the permeability and improves durability.

In order to measure the effect of the Super-Pozz® on the workability, water requirement and HRWR dosage, three series of concrete mixes were prepared, based on the following mix design methodology:

- A. **Workability:** Keeping the w/b ratio (binder= cement + extender) and HRWR content constant and measuring the variation of the slump
- B. **Water Demand:** Keeping HRWR dosage the same and varying the amount of water required to achieve the same slump
- C. **Admixture Requirement:** Keeping the w/b ratio the same and varying the amount of HRWR required to maintain similar slump measurements.

In all 3 series, Super-Pozz was used at replacement levels of 5%, 10%, 15% and 20% of the total binder content. For silica fume mixes, replacement levels of 5% and 10% were used. The total binder content was kept constant at 400kg/m³. Crushed dolerite with a specific gravity of 2.92 served as the coarse aggregate. The sand content was a blend of dolerite crusher sand and filler sand with a specific gravity of 2.82. Prior to their use, the materials were completely dried. The cement used was CEM I 42.5. The HRWR was a naphthalene-based admixture.

On all mixes, compressive strengths were measured at 1, 3, 7, 28, 56 and 90 days. Water permeability and absorption as well as chloride permeability were used to evaluate durability. Workability was measured in terms of slump and the target slump was 125mm.

EXPERIMENTAL PROGRAMME

With the exception of HRWR and water, the mass of the mix constituents remained the same in all 3 series (Table 3). Using this as a starting point, the design for a specific series A, B, C was then characterized by a particular water and HRWR content. Mix 1, using plain OPC (CEM I 42.5) as the binder served as the control mix.

Table 3: Mix formulations of dry constituents used to prepare specimens in all series

Mass of Constituents							
Reference	1	2	3	4	5	6	7
Extender	Nil	5% CSF	10% CSF	5% S/Pozz	10% S/Pozz	15% S/Pozz	20% S/Pozz
CEM I 42.5	400	380	360	380	360	340	320
Silica Fume	-	20	40	-	-	-	-
Super-Pozz	-	-	-	20	40	60	80
Crusher Sand	600	600	600	600	600	600	600
Filler Sand	195	175	155	175	155	155	155
C/ Aggregate	1080	1100	1120	1100	1120	1120	1120

*CEM I 42.5 – Ordinary Portland Cement *CSF – Silica Fume

*S/Pozz – Super-Pozz

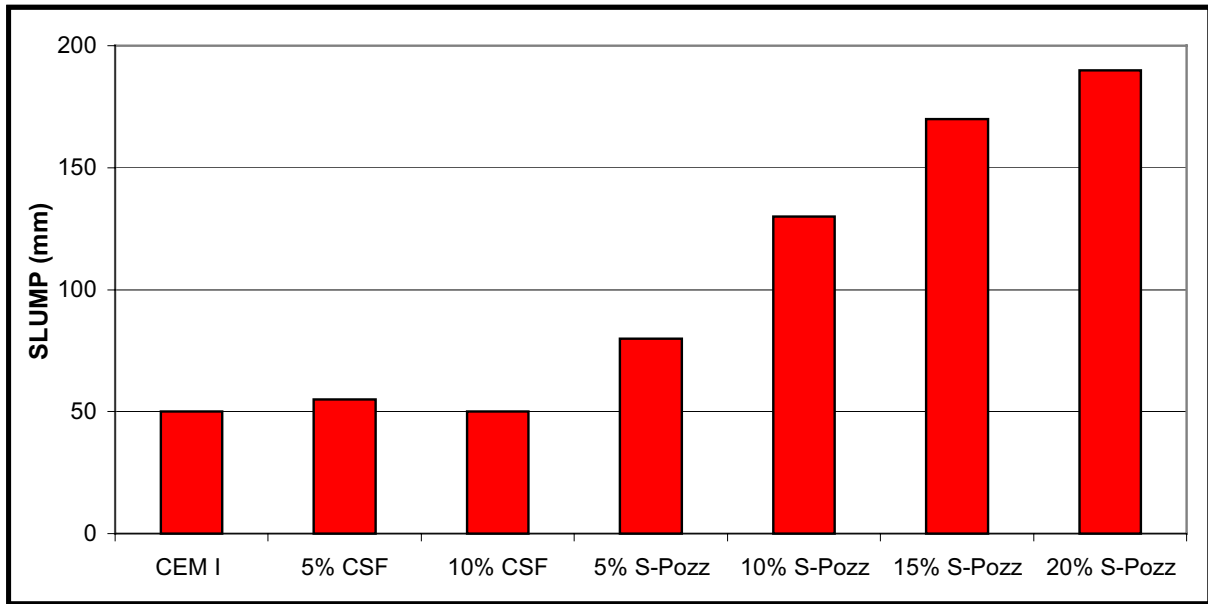
SERIES A: EVALUATION OF WORKABILITY

Table 4 and Figure 2 shows that the replacement of a portion of cement with Super-Pozz, improves the workability of the concrete substantially. If all constituents of the mix are equal i.e. w/b ratio and admixture content, the introduction of Super-Pozz provides a major increase in workability. For series A, 5.2 ltrs/m³ of HRWR and 152 ltrs/m³ of water (w/b 0.38) were used throughout. As can be seen from the data in Table 4 the slump increased with the amount of Super-Pozz used. The increase in workability can be ascribed to the morphology of the Super-Pozz. In particular the sphericity of the particles enables them to “roll” in the concrete mix. This “ball-bearing” or lubricating effect aids flow and increases the slump.

Table 4: Workability data for concrete specimens of equal w/b ratio and containing the same amount of HRWR

EVALUATION OF WORKABILITY							
Reference	A1	A2	A3	A4	A5	A6	A7
Extender	Nil	5% CSF	10% CSF	5% S-Pozz	10% S-Pozz	15% S-Pozz	20% S-Pozz
Water (Itrs)	152	152	152	152	152	152	152
HRWR (liters)	5.2	5.2	5.2	5.2	5.2	5.2	5.2
Slump (mm)	50	55	50	80	130	170	190

Figure 2: Evaluation of Workability



The rates of strength development of these concrete mixes (Series A) are given in Table 5. It will be noted that while the specimens containing silica fume initially developed strength more rapidly, at 90 days the compressive strength of the specimens containing the Super-Pozz was the same. This indicates that the Super-Pozz exhibits latent pozzolanicity.

Table 5: The effect of the addition of Super-Pozz on the rate of development of compressive strength for concrete specimens of equal w/b ratio and containing the same amount of HRWR.

COMPRESSIVE STRENGTH (MPa)							
Reference	A1	A2	A3	A4	A5	A6	A7
Extender	Nil	5% CSF	10% CSF	5% S-Pozz	10% S-Pozz	15% S-Pozz	20% S-Pozz
1 day	18.5	19.5	19.5	16.0	15.0	14.0	13.5
3 day	38.5	38.5	38.5	35.0	31.5	30.0	28.0
7 day	55.5	53.0	57.0	52.5	46.5	46.5	44.5
28 day	72.5	81.0	88.0	69.5	73.0	73.0	71.5
56 day	81.0	88.0	94.0	79.0	81.0	87.5	79.5
90 day	82.0	88.5	98.5	91.5	91.0	92.0	97.5

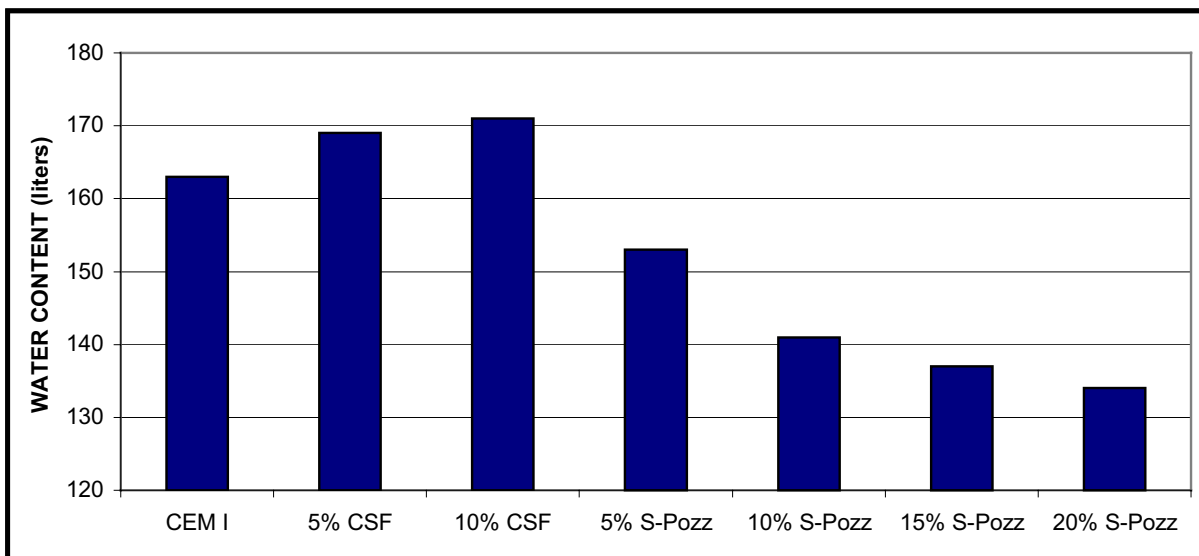
SERIES B: EVALUATION OF WATER DEMAND

One of the main features expected of Super-Pozz is, by virtue of its sphericity and ideal particle size distribution, is to reduce the amount of water required to achieve a specific slump value. In this series, the binder content, HRWR content and workability were kept constant and the effect of water requirement measured. The HRWR was dosed at 5.2ltrs/m³ (1.3% wt of binder).

Table 6: The effect of Super-Pozz on the water required to maintain a constant slump

EVALUATION ON WATER REQUIREMENT							
Reference	B1	B2	B3	B4	B5	B6	B7
Extender	Nil	5% CSF	10% CSF	5% S-Pozz	10% S-Pozz	15% S-Pozz	20% S-Pozz
Water (liters)	163	169	171	153	141	137	134
HRWR (liters)	5.2	5.2	5.2	5.2	5.2	5.2	5.2
W/b ratio	0.41	0.42	0.43	0.38	0.35	0.34	0.33
Slump (mm)	130	130	125	140	125	130	140

Figure 3: Evaluation of Water Requirement



The results from Table 6 and Figure 3 shows that the formulations containing silica fume required more water than their Super-Pozz counterparts to achieve a slump of about 125mm. The water demand of concrete decreased along with the amount of cement replaced by Super-Pozz.

Table 7: The compressive strength for specimens of equal HRWR and slump

COMPRESSIVE STRENGTH (MPa)							
Reference	B1	B2	B3	B4	B5	B6	B7
Extender	Nil	5% CSF	10% CSF	5% S-Pozz	10% S-Pozz	15% S-Pozz	20% S-Pozz
1 day	15.5	15.5	13.5	15.0	20.5	17.0	15.0
3 day	35.0	32.5	30.0	35.0	40.0	36.5	35.0
7 day	52.0	48.5	47.0	50.58	58.5	56.5	52.5
28 day	70.5	77.5	78.5	69.5	82.0	85.0	81.0
56 day	80.0	80.5	84.0	84.0	91.5	91.5	97.0
90 day	81.0	81.0	79.0	86.0	93.5	102.5	93.5

At constant binder content, the compressive strength of concrete increased along with a reduction in the w/b ratio. The incorporation of Super-Pozz in concrete facilitates a lower w/b ratio and as a result, improved compressive strength is achieved at all ages. After 56 days the compressive strength achieved by the mixes containing Super-Pozz exceeded that of the mixes containing silica fume.

As a result of the ongoing pozzolanic reaction the concrete specimens containing Super-Pozz showed a far higher rate of gain in strength between 28 and 90 days than their silica fume counterparts.

SERIES C: EVALUATION OF HRWR REQUIREMENT

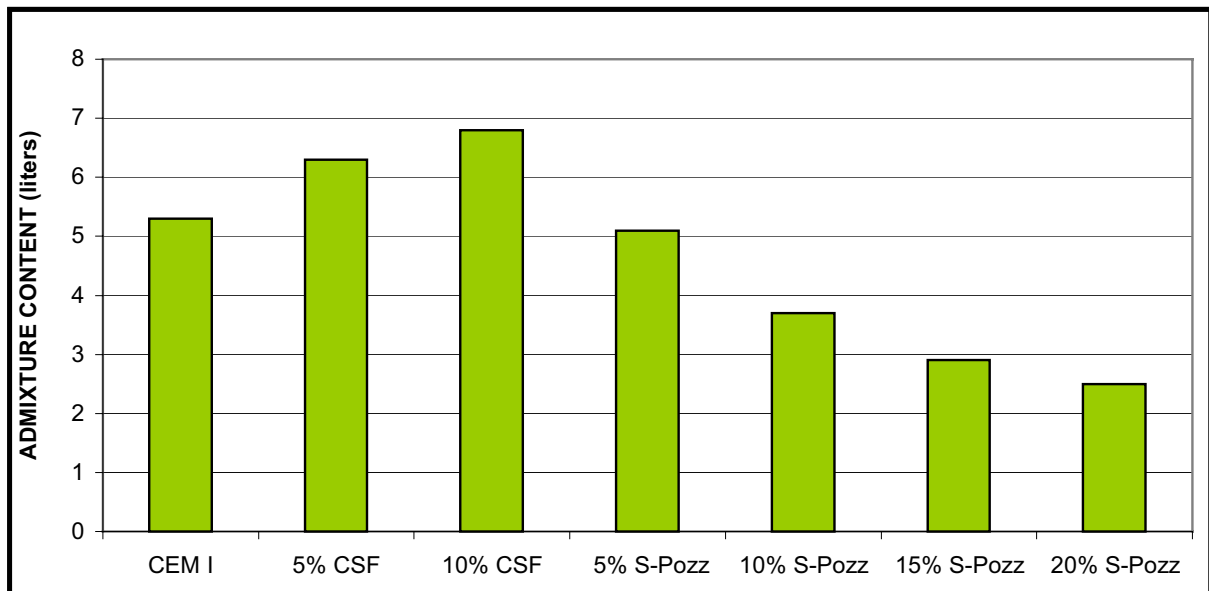
For concrete where compressive strength is easily achievable, lower admixture content can be used to attain the desired workability. Due to the particle shape and size of Super-Pozz, workable concrete can be made using less admixture content.

For the C series, both workability and water content (152 liters/m³) were kept constant and the amount of HRWR required for a slump of about 125mm was measured.

Table 8: Evaluation of the amount of HRWR required maintaining similar slumps in concrete containing Super-Pozz and silica fume

EVALUATION OF HRWR REQUIREMENT							
Reference	C1	C2	C3	C4	C5	C6	C7
Extender	Nil	5% CSF	10% CSF	5% S-Pozz	10% S-Pozz	15% S-Pozz	20% S-Pozz
W/b ratio	0.38	0.38	0.38	0.38	0.38	0.38	0.38
HRWR (liters)	5.3	6.3	6.8	5.1	3.7	2.9	2.5
Slump (mm)	150	140	130	135	130	125	125

Figure 4: Evaluation of Admixture Requirement



From the results in Table 8 and Figure 4, it can be seen that in order to maintain the same workability, concrete containing 10% Super-Pozz reduces the HRWR requirement whilst silica fume increases it. Generally, when silica fume is used in concrete, its performance is enhanced by the variable HRWR addition used to control water demand. With Super-Pozz, the situation is changed. Super-Pozz provides a lower HRWR dosage or alternatively a normal water-reducing admixture (plasticiser) can be used instead as a minimum to achieve the desired workability.

Table 9: The compressive strengths for concrete specimens of equal slump and w/b ratio

COMPRESSIVE STRENGTH (MPa)							
Reference	C1	C2	C3	C4	C5	C6	C7
Extender	Nil	5% CSF	10% CSF	5% S-Pozz	10% S-Pozz	15% S-Pozz	20% S-Pozz
1 day	17.0	25.0	22.5	24.0	20.0	21.5	16.5
3 day	44.5	55.0	49.5	53.0	46.0	43.0	37.5
7 day	60.0	70.5	69.0	75.0	65.0	59.0	57.5
28 day	83.5	92.0	97.0	92.0	80.0	87.5	82.5
56 day	91.5	101.0	99.5	99.0	99.5	99.5	95.0
90 day	93.0	89.0	105.0	103.5	100.0	106.0	103.0

At all ages, mixes containing comparable amounts of Super-Pozz and silica fume exhibited similar rates of strength development (Table 9). At higher replacement levels the pozzolanic behavior of Super-Pozz is responsible for significant rates of gain in strength at later ages.

DISCUSSION OF MIX DESIGN CRITERIA AND THEIR TEST RESULTS

The foregoing vividly illustrates the importance of understanding the factors that influence the rate of strength development in concrete mixes containing Super-Pozz. In order to maximise the benefits of fineness, sphericity and pozzolanic activity of Super-Pozz, particular attention must be given to mix design criteria.

In the first instance, using the same amount of water and superplasticiser in concrete mixes containing Super-Pozz, as used in comparable concrete with silica fume, results in large increase in slump. This is mainly due to the sphericity of Super-Pozz, which facilitates flow. As can be expected, the concrete with higher slumps exhibited a slower initial rate of strength development. At later ages (90 days) the compressive strength of concretes with Super-Pozz was similar to those containing silica fume.

If, however the amount of water or superplasticiser used in the mix is adjusted and the concretes are designed to have similar slumps, the picture changes entirely. Not only are the rates of strength development comparable but also due to its latent pozzolanic activity, the compressive strength of the mixes containing Super-Pozz exceeds those with silica fume.

The long-term pozzolanic activity of Super-Pozz can be seen as a function of its particle size distribution. Silica fume is much finer than the Super-Pozz. As a result of the higher surface area the pozzolanic reaction proceeds rapidly and strength is quickly developed. The downside

of this is that as the surface of the silica fume becomes covered with the reaction products the $\text{Ca}(\text{OH})_2$ can no longer reach and the pozzolanic reaction slows down. Super-Pozz on the other hand has a wider range of particles sizes. As the finer particles are covered and thus prevented from participation in further reaction, the larger particles still remain available. The pozzolanic reaction can thus still proceed at later ages.

The above is certainly not the definitive explanation since the glass content of the pozzolan as well as the composition and concentration of both alkaline and alkali hydroxides influence the rate and extent of the pozzolanic reaction. Nevertheless the higher rate of strength development exhibited at later ages by Super-Pozz must necessarily take the difference of particle size distribution into account.

DURABILITY

While strength development is an important criterion for concrete performance, it fails to give an insight into durability. Durability was assessed by means of a series of tests designed to measure the density and impermeability of the binder paste microstructure. Water permeability and absorption as well as chloride permeability were measured. Probably the most important consideration when using Super-Pozz, is its ability to improve the durability of concrete by decreasing the water demand without adversely affecting the workability. Thus, samples for the durability tests were prepared using series “A” specimens i.e. constant slump and HRWR, taking into effect the water reducing properties of Super-Pozz.

Water permeability

The DIN 1048 test method was used to measure the impermeability of concrete. In this test, slabs initially water-cured for 28 days, are then exposed to a water pressure of 5 bars for 72 hours after which the slab is split and the depth of water penetration measured. Penetration of less than 25mm is generally considered to be impermeable concrete

Table 10: Water permeability (DIN 1048)

WATER PERMEABILITY (mm)					
CEM I 42.5	5% CSF	10% CSF	5% S-Pozz	10% S-Pozz	15% S-Pozz
19	8	14	12	6	18

As can be seen, the results achieved generally fell within the range of 5 to 20mm with the 10% Super-Pozz mix showing the best resistance to water penetration.

Water Absorption

In this test the cubes are initially water cured for 28 days, following which cores are drilled out and oven dried for 72 hours before once again being immersed in water. The increase in mass resulting from the immersion is expressed as a percentage of the dry specimen. Higher water absorption figures are indicative of permeable concrete.

As can be seen from the results obtained in Table 11, concrete specimens containing Super-Pozz have the lowest absorption values. This is indicative of a denser microstructure. The decrease in values from 28 to 56 days reflects an increase in density as the result of the refinement of the pore structure.

Table 11: Water Absorption (BS 1881: Part 118)

WATER ABSORPTION (%)						
	CEM I	5% CSF	10% CSF	5% S-Pozz	10% S-Pozz	15% S-Pozz
28 day	1.70	1.61	1.56	1.53	1.41	1.38
56 day	1.67	1.58	1.45	1.47	1.32	1.25

Chloride Permeability

The Rapid Chloride Permeability Test (ASTM 1202) measures the total charge (coulombs) flowing through a 2 inch thick concrete specimen during 6 hours of applied potential of 60V. The test is conducted on cores, cured in water for 28 days or longer. The one end of the specimen is immersed in NaCl solution, the other in NaOH. The total charge passing through is regarded as a measure of the resistance of concrete to the diffusion of chloride ions. The higher the charge the easier the ions migrate and the poorer the concrete.

Table 12: Chloride permeability (ASTM C1202)

CHLORIDE PERMEABILITY (Coulombs)						
	CEM I 42.5	5% CSF	10% CSF	5% S-Pozz	10% S-Pozz	15% S-Pozz
28 day	2206	1329	898	1987	1254	1481
56 day	1798	772	445	1368	870	816

The results obtained (Table 12), substantiates the fact that cement extenders decreases the permeability of concrete. This is mainly attributed to the conversion of Ca(OH)_2 to calcium silicate hydrates. Although it would appear that silica fume mixes are more resistant to chloride diffusion, the mixes containing Super-Pozz continue to develop strength at later ages. This on-going refinement of the pore structure will be accompanied by a concomitant reduction in chloride diffusion.

SUMMARY

Results obtained show that Super-Pozz can be used as a viable substitute for silica fume. If the advantages of Super-Pozz are exploited in the concrete mix design, the initial rate of strength development was found to be the same or similar to those of silica fume mixes. At later ages, however, the pozzolanic activity of Super-Pozz leads to higher compressive strength values.

Durability test measuring the water permeability and absorption as well as chloride permeability showed comparable values for both silica fume and Super-Pozz mixes.

The use of Super-Pozz, as an alternative to silica fume can be effective in enhancing the properties of concrete, both in its fresh and hardened state. Due to the lower water demand required, Super-Pozz can be ideally used to:

- Lower the water/binder ratio
- Use of more cost-effective admixture dosages; or
- A combination of the above

TECHNICAL BENEFITS

During the last year extensive trials have been conducted, at various institutions and organizations to assess the properties of Super-Pozz and its performance in concrete. These extensive trials have shown the following benefits:

- Reduced water demand ~ higher strengths, lower shrinkage
- The use of more cost effective admixture dosages
- Improved workability and flow characteristics
- Higher early strengths and better ultimate strengths
- Improved durability
- Lower shrinkage

APPLICATIONS

The use of Super-Pozz offers exciting opportunities in various cementitious applications. Among these are:

- High Performance Readymix and Precast concrete
- Self-Compacting concrete (SCC)
- Spray concrete i.e. Shotcrete and Guniting applications
- Specialist Grouts
- Self-leveling floor screeds, precision grouts and repairs
- Propriety Pre-mix formulations

Future developments will probably see the co-utilization of Super-Pozz and silica fume. With the ever increasing need to provide stronger more durable concrete, the lower water content required by Super-Pozz will provide civil engineers with the opportunity to simultaneously exploit the best properties of both products.

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