10.102 – POZZOLANIC ACTIVITY INDEX (COMPRESSIVE STRENGTH OF MORTARS)

High Reactivity Metakaolin (HRM)
Engineered Mineral Admixture for Use with Portland Cement

Advanced Cement Technologies' PowerPozz™ High Reactivity Metakaolin is a manufactured pozzolanic mineral admixture which significantly enhances many performance characteristics of cement-based mortars, concretes and related products.

PowerPozz™, derived from purified kaolin clay, is a white, amorphous, alumino-silicate which reacts aggressively with calcium hydroxide, a normal cement hydration byproduct, to form compounds with cementitious value.

Testing Program

Advanced Cement Technologies has performed an evaluation of the performance of *PowerPozz™* HRM in cement mortars. The purpose of the testing (in accordance with ASTM C-311 / ASTM C-618) was to demonstrate the pozzolanic activity index of *PowerPozz™* HRM over that of a control, or in some cases, as compared to other pozzolans.

The evaluations, conducted at the facilities of **AGRA Earth and Environmental in Vancouver, B.C., Canada,** were conducted in **three phases**:

In Phase 1, *PowerPozz™* was used in varying concentrations (5,10, 15%) and compared to the same concentrations of silica fume and to a plain cement control. Strengths and the variations in required superplasticizer dosage were examined.

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In Phase 2, the mixes were produced with a range of different pozzolans, including *PowerPozz™* without superplasticizers. The water addition and therefore water to binder ratios were allowed to vary to achieve similar flows. Effects on water demand and strength were examined.

In Phase 3, the compressive strength of a plain cement mortar was compared with the strength gain of a mortar in which 10% of the cement was replaced with *PowerPozz™ HRM.* In this study, a dry superplasticizer was added to both the control and the test mixes at a constant dosage. Both the control and test mixes were produced at a water / binder ratio of 0.40 and a sand / binder ratio of 2.75. Compressive strengths presented are the averages for 3 cubes at each of the 4 age intervals (1,3,7,28 days).

PHASE 1

Methodology

In this study, 9 mortar mixes were produced: Two of the mixes were Class F Flyash/HRM combinations and will be reported separately. For the remaining **7 mixes**, the following cementitious materials were used:

Mix 1:	Type 1 Ordinary Portland Cement (Control)
Mix 2:	OPC / 5% *PowerPozz™* HRM
Mix 3:	OPC / 10% *PowerPozz™* HRM
Mix 4:	OPC / 15% *PowerPozz™* HRM
Mix 5:	OPC / 5% Silica Fume
Mix 6:	OPC / 10% Silica Fume
Mix 7:	OPC / 15% Silica Fume

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The percentages of supplementary cementing materials were **replacements** by weight of portland cement, **not additions**.

The mortars were produced with a **water : binder ratio of 0.40**.

The compressive strength results reported are the averages of two cubes

Phase 1 Results

Results from Phase 1 are reported in Table 1.

Project: Comparative Strength Testing of *PowerPozz™* High Reactivity Metakaolin

Subject: Strength Activity Index with Portland Cement (ASTM C-311)

TABLE 1. Phase 1

TEST DATA							
	Mix 1	**Mix 2**	**Mix 3**	**Mix 4**	**Mix 5**	**Mix 6**	**Mix 7**
Materials	**Control**	**5% PP HRM**	**10% PP HRM**	**15% PP HRM**	**5% Silica Fume**	**10% Silica Fume**	**15% Silica Fume**
Type 1 Cement (g)	667	633	600	567	633	600	567
PowerPozz™ (g)	-	34	67	100	-	-	-
Silica Fume (g)	-	-	-	-	34	67	100
Standard Sand	1428	1428	1428	1428	1428	1428	1428
Superplasticizer, Daxad 199g)	0.42	0.80	1.67	2.52	1.25	3.29	5.55
Water (g)	267	267	267	267	267	267	267
W/C Ratio	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Flow, at 15 drops of flow table (%)	115	115	115	120	110	125	115

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TEST RESULTS							
Compressive Strength (Mpa)	23.4	25.3	27.6	28.0	24.1	28.8	29.8
Strength Activity Index @ 24 hrs.	1.0	1.05	1.15	1.17	1.03	1.20	1.24
Compressive Strength (Mpa)	41.0	42.7	47.7	49.0	44.2	44.0	45.0
Strength Activity Index @ 3 Days	1.0	1.04	1.16	1.2	1.08	1.07	1.1
Compressive Strength (Mpa)	48.7	54.0	60.2	62.9	53.7	60.9	62.9
Strength Activity Index @ 7 Days	1.00	1.11	1.24	1.29	1.10	1.25	1.29
Compressive Strength (Mpa)	57.7	63.4	70.4	73.7	66.7	76.1	78.9
Strength Activity Index @ 28 Days	1.00	1.10	1.22	1.28	1.16	1.32	1.37
Compressive Strength (Mpa)	55.7	64.2	68.8	76.1	67.3	74.2	77.7
Strength Activity Index @ 56 Days	1.00	1.15	1.24	1.37	1.21	1.33	1.39
*56 day results are based on 1 cube only							

Phase 1 Results & Discussion

The results show that both mineral admixtures show progressive increases in strength with increasing percentages of replacement, up to the 15% level.

With *PowerPozz™* at 5% replacement, the strength increase is 10% over control. At 10% and 15% replacements, *PowerPozz™* contributed to 22% and 28% gains respectively as compared to the control mix.

The results indicate that increasing loading rates of *PowerPozz™* contribute to higher strengths.

These results also indicate that *PowerPozz™* is **most efficient within the range of 10 ± 2%**. At 5% *PowerPozz™*, a 2% increase in strength is realized per percent *PowerPozz™*. This increases to a 2.2% increase in strength per percent *PowerPozz™* at 10% replacement and decreases slightly to 1.9% per percent *PowerPozz™* at the 15% replacement level.

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In comparing the *PowerPozz™* HRM mixes to those produced with silica fume, *PowerPozz™* mortars were generally stronger at three days, approximately the same at seven days and slightly lower at 28 days.

These results show that *PowerPozz™* is comparable to silica fume in terms of compressive strength development but does so with a much **lower water demand**. Therefore, the *PowerPozz™* mortars required a significantly lower (half) dosage of superplasticizer to maintain flow and stable water: cementitious ratio. The pozzolanic activity results without the use of superplasticizers are examined in Phase 2.

It was observed that with *PowerPozz™* being **white in color**, it produced mortars which were fairly normal in appearance, whereas those produced with silica fume had a characteristic dark gray color.

PHASE 2

Methodology

In the second study, the mortars were produced in accordance with ASTM C-311.

One control (plain OPC) mix was produced, and all other supplementary cementing materials were used at 7.5% replacement by weight of cement. Five mixes are reported here. Of the five mixes one was the control, one included silica fume, and three were produced with metakaolins. Of the three HRM products used, one is *PowerPozz™*, and the other two are other commercially available metakaolins.

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Mix 1:	OPC - Ordinary Portland Cement (Control)
Mix 2:	OPC / Metakaolin A
Mix 3:	OPC / Metakaolin B
Mix 4:	**OPC / *PowerPozz™***
Mix 5:	OPC / Silica Fume

The control mix was produced with a **water : cement ratio of 0.48**. The subsequent mixes containing the supplementary cementing materials had constant cementitious contents with water being adjusted to achieve a flow similar to the control mix. As a result, the **water : binder ratios for the HRM and silica fume mixes varied**. No water-reducing admixtures were used in this Phase.

Phase 2 Results

The results of the tests for Phase 2 are presented in Table2.

The control mix had the lowest water : cementitious ratio, and the silica fume mix had the highest.

The greatest strength was achieved with 7.5% replacement with *PowerPozz™*.

The silica fume mix, with a relatively high water demand and w / c ratio, had strengths similar to control. For this reason, silica fume is seldom, if ever, used or recommended without superplasticizing admixtures.

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Table 2

Project: Comparative Testing of Mineral Admixtures
Subject: Strength Activity Index with Portland Cement (ASTM C-311 Modified)

TEST DATA					
	Mix 1	**Mix 2**	**Mix 3**	**Mix 4**	**Mix 5**
Type 1 Cement (g)	667	617	617	617	617
Graded Standard Sand (g)	1427.8	1427.8	1427.8	1427.8	1427.8
Metakaolin "A" (g)	-	50	-	-	-
Metakaolin "B" (g)	-	-	50	-	-
PowerPozz™ HRM (g)	-	-	-	50	-
Silica Fume (g)	-	-	-	-	50
Water (g)	322.7	357.8	335.5	336.0	372.9
W / C Ratio	0.483	0.536	0.503	0.504	0.559
Flow (%)	98±5	93±5	94±5	94±5	99±5

TEST RESULTS					
Compressive Strength (Mpa)	43.7	35.0	38.2	39.7	29.3
Compressive Strength (Mpa)	52.7	51.9	49.4	52.7	45.7
Compressive Strength (Mpa)	64.4	57.0	66.9	73.3	64.5

Comments: ASTM C-311 was modified by replacing the standard Ottawa sand (as designated in ASTM C778) with a fine industrial sand similar in composition.
The flow rates were kept constant by varying the water : cementitious ratios.

Phase 2 Results & Discussion

The *PowerPozz™* mix showed a much **lower water demand** than those produced with silica fume. If this effect is compensated for by employing superplasticizing admixtures, as in Phase 1, the silica fume can produce somewhat higher strengths, but with a much higher dosage of superplasticizer.

Products produced with *PowerPozz™* or other metakaolins are significantly **lighter in color** than those produced with silica fume at normal addition rates.

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The 28-day compressive strength of the mortar containing 7.5% *PowerPozz™*, with no superplasticizers, at a 0.40 water : cement ratio **exceeded all samples** tested in Phase 1.

At 7.5% replacement, the *PowerPozz™* mortar was 9.6% higher in compressive strength than other metakaolin samples, and was 13.6% higher than the silica fume and control mortars.

PHASE 3

In this phase, the compressive strength of a plain cement mortar was compared with the strength gain of a mortar in which **10% of the cement was replaced with *PowerPozz™ HRM.*** In this study, a dry superplasticizer was added to both the control and the test mixes, and all were produced at a water / binder ratio of 0.40 and a sand / binder ratio of 2.75. Compressive strengths presented are the averages for 3 cubes at each of the 4 age intervals (1,3,7,28 days).

Table 3

TEST DATA				TEST RESULTS			
Material	**Contro**	**10%PowerPoz**			**Control**	**10% PowerPozz**	**Pozz**
Type 1 Cement (g)	1000	900		1 Day	20.9	23.2	1.11
Graded Standard Sand (g)	2750	2750		3 Days	46.1	50.0	1.09
PowerPozz™ HRM (g)	0	100		7 Days	52.2	64.3	1.23
Water (g)	400	400		28 Days	64.1	82.8	1.29
Water / Binder Ratio	0.40	0.40					
Superplasticizer (Daxad 19)	3.0	3.0					
Flow (%)	90	90					

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Phase 3 - Results & Discussion

It is noteworthy that even with a 10% replacement of cement by 1:1 substitution of pozzolan (metakaolin) the **early strengths** (1,3 Days) demonstrated a positive (>1) index over control. This is indicative of the early reactivity of *PowerPozz™* HRM. The early age pozzolanic reactivity and strength performance is a unique and defining feature of metakaolin, as compared to other pozzolanic materials.

It is also apparent from these results that HRM continues to indicate increasing pozzolanic reactivity at an increasing rate within the 28-day period of study. It would be normal to expect that the strength gain differential between the HRM test mix and the plain cement control will continue to widen over the long run of time. This conclusion has been made through our own research and is well corroborated by others with regard to pozzolans in general, and also specifically where HRM and like materials are concerned.

The **high pozzolanic reactivity** of *PowerPozz™* HRM makes it, of course, an important input ingredient for the formulation of **high strength materials**. In fact, when mix design options with and without HRM are examined, it is normal to find that to increase the strength of a performance concrete, it is often more efficient to utilize HRM than to increase the cement content.

For concretes within the normal design compressive strength range, the performance advantages of HRM may also be important (i.e.: low permeability, high chemical resistivity, corrosion mitigation, control of efflorescence or ASR, etc.). In these mix designs, it may be possible to use HRM as a substitute for cement, for example at a 10% wt cement replacement level, and also reduce the total cementitious content of the mix and still met the design strength requirements comfortably.

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These figures and examples are presented for illustrative and descriptive purposes only. Only a properly conducted trial batch and testing program

will determine actual performance for a particular mix design, application, or set of raw materials.

Ask your ACT representative for assistance in the development of mix designs with metakaolin.

PowerPozz™ **is a mineral admixture, which offers excellent performance and can contribute to the manufacture of high strength, high durability mortars, concretes and related portland cement-based products.**

All information, while provided in good faith, with every effort made to assure accuracy, is provided by Advanced Cement Technologies at no charge, and with warranty--express or implied. Data given, unless otherwise stated, are based on standard testing procedures which are available on request. Variations do occur in individual tests and the results stated herein cannot be taken for minima or maxima for specification purposes.

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