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MetaMax®
High Reactivity Metakaolin (HRM) for Improved Pre-cast Concrete

A Moist-cured & Hot-water-cured Study

C-8-E, 1/97

MetaMax® High Reactivity Metakaolin (HRM) for Improved Pre-cast Concrete

MetaMax® *High Reactivity Metakaolin (HRM) is a white, thermally activated aluminosilicate that is manufactured by Engelhard Corporation specifically to improve the performance of cement-based products.* ***MetaMax*** *metakaolin is produced in an ISO-9002 certified facility using statistical process quality control (SPQC) to ensure a consistent, uniform and highly reactive pozzolanic mineral admixture.*

This study shows that replacing an ASTM C-150 Type I cement with ***MetaMax*** *significantly increases the concrete strength as early as one day when normal or accelerated curing was used.* ***MetaMax*** *produces a dense cement paste by reacting with the free lime ($Ca(OH)_2$) that forms as a by-product of the portland cement hydration. Because of this pozzolanic reaction, not only can strength be increased, but enhancements including reduced permeability and increased chemical resistance can be achieved.*

INTRODUCTION

This report summarizes a laboratory study of two typical pre-cast concrete formulations that contained ***MetaMax*** HRM. The concrete mixtures were re-formulated using ***MetaMax*** as a replacement for a small portion of the portland cement. The tests were performed at Rutger's University under the guidance of Professor P. Balaguru in Piscataway, New Jersey.

The evaluation included plastic tests of air content, unit weight and slump cone measurements and hardened concrete tests of compressive strength, modulus of elasticity and modulus of rupture. Two types of curing were used: one in 100% relative humidity at 70°F and the other in warm water maintained at 122°F.

Replacements of cement with silica fume, another highly reactive pozzolan, were included as a reference to compare the activity of ***MetaMax***. The amount of high-range water reducer (superplasticizer) was kept constant for each concrete mixture. Because of the reduced workability of the concrete containing silica fume, the superplasticizer additions for each formulation were dictated by the silica fume mixtures.

RESULTS

5000 psi Concrete Mixture Design

In this 5000 psi design mixture, 5% by weight of an ASTM C-150 Type I cement was replaced with either ***MetaMax*** or densified silica fume. The water-to-cementitious ratio was maintained at 0.40 for all of the concrete mixtures. Both an ASTM C-494 Type A and Type F water reducer were used in the mixture. Air entraining admixture was added to achieve a target air content of 6-8%.

The mixture proportions are in Table 1. Table 2 shows the fresh concrete properties. The hardened concrete properties are in Table 3. For each of the strength measurements, two cylinders were averaged.

Table 1. Concrete Mixture Proportions per cubic yard.

	Control	5% ***MetaMax***	5% Silica Fume
Type I cement (lb)	517	491	491
MetaMax (lb)	0	26	0
Silica fume (lb)	0	0	26
Fine Aggregate (lb)	1320	1320	1320
Coarse Aggregate (lb)	1850	1850	1850
Water (lb)	207	207	207
Type A water reducer (oz.)	17	17	17
Type F high-range water reducer (oz.)	132	132	132
Air-entraining admixture (oz.)	5	5	5

Table 2. Fresh Concrete Properties.

	Control	5% ***MetaMax***	5% Silica Fume
Slump (in.)	5½	7	2¾
Air Content (%)	7.0	6.5	6.0
Temperature (°F)	77	75	75
Unit Weight (lb/ft^3)	157.8	158.6	158.6

Table 3. Hardened Properties of Moist-cured Concretes.

	Control	5% ***MetaMax***	5% Silica Fume
TESTING AGE (days)	COMPRESSIVE STRENGTH (psi)		
1	3110	3660	3920
2	4480	4440	3780
3	4620	6010	5400
28	5810	7700	7860
56	6990	8270	8740
90	7850	9320	9640
TESTING AGE (days)	MODULUS OF ELASTICITY (ksi)		
1	4830	4900	4590
2	5070	5060	5540
3	5310	5620	5380
28	6070	6590	6160
TESTING AGE (days)	MODULUS OF RUPTURE (psi)		
28	800	960	880

Because fast form turnaround is a necessity in pre-cast operations, accelerated curing is often used. The effect of accelerated curing on the non-pozzolanic control concrete and the concrete containing ***MetaMax*** was studied. The curing was maintained at 122°F for three days. Cylinders of each of the two concretes were removed from the 122°F water bath after three days and were kept at room temperature in the laboratory, not in the moist-curing room until 28 days for testing. Table 4 shows the hardened properties of concretes that were cured using the accelerated curing method.

Table 4. Hardened Properties of Hot-water-cured (122°F) Concretes.

	Control	5% ***MetaMax***
TESTING AGE (days)	COMPRESSIVE STRENGTH (psi)	
1	3900	4100
2	4560	5240
3	4740	5770
28	4870	6450
TESTING AGE (days)	MODULUS OF ELASTICITY (ksi)	
1	5100	5600
2	5240	5970
3	5240	6070
28	5380	6160

9000 psi Concrete Mixture Design

Concretes were made with a design strength of 9000 psi. In this formulation, 9% by weight of an ASTM C-150 Type I cement was replaced with either ***MetaMax***® metakaolin or densified silica fume. The water-to-cementitious ratio was maintained at 0.35 for all of the concrete mixtures. Both an ASTM C-494 Type A and Type F water reducer were used in the mixture. No air entraining admixture was added.

The mixture proportions are in Table 5. Table 6 shows the fresh concrete properties. The hardened properties of the moist-cured concretes are listed in Table 7. For each of the strength measurements, two cylinders were averaged.

Table 5. Concrete Mixture Proportions per cubic yard.

	Control	9% ***MetaMax***	9% Silica Fume
Type I cement (lb)	850	774	774
MetaMax (lb)	0	76	0
Silica fume (lb)	0	0	76
Fine Aggregate (lb)	1200	1200	1200
Coarse Aggregate (lb)	1750	1750	1750
Water (lb)	298	298	298
Type A water reducer (oz.)	17	17	17
Type F high-range water reducer (oz.)	132	132	132

Table 6. Fresh Concrete Properties.

	Control	9% ***MetaMax***	9% Silica Fume
Slump (in.)	8	8	2½
Air Content (%)	5.0	3.5	4.0
Temperature (°F)	76	77	78
Unit Weight (lb/ft^3)	155.2	158.6	156.9

Table 7. Hardened Properties of Moist-cured Concretes.

	Control	9% *MetaMax*	9% Silica Fume
TESTING AGE (days)	COMPRESSIVE STRENGTH (psi)		
1	5930	4420	5180
2	5740	6370	6470
3	6540	7720	7340
28	8980	11290	10510
56	11180	12940	12140
90	11780	13890	12660
TESTING AGE (days)	Modulus of Elasticity (ksi)		
1	4390	4250	3820
2	4840	4500	4500
3	5100	4840	5030
28	5460	6270	5540
TESTING AGE (days)	MODULUS OF RUPTURE (psi)		
28	1150	1110	1110

Because fast form turnaround is a necessity in pre-cast operations, accelerated curing is often used. The effect of accelerated curing on the non-pozzolanic control concrete and the concrete containing ***MetaMax*** was studied. The curing was maintained at 122°F for three days. Cylinders of each of the two concretes were removed from the 122°F water bath after three days and were kept at room temperature in the laboratory, not in the moist-curing room until 28 days for testing. Table 8 shows the hardened properties of the concretes cured with accelerated curing.

Table 8. Hardened Propeerties of Hot-water-cured (122°F) Concretes.

	Control	9% *MetaMax*
TESTING AGE (days)	COMPRESSIVE STRENGTH (psi)	
1	6130	6470
2	7100	7300
3	7240	7980
28	9030	9450
TESTING AGE (days)	MODULUS OF ELASTICITY (ksi)	
1	5030	5970
2	5030	5970
3	5100	5970
28	5300	6070

CONCLUSIONS

Fresh Concrete Properties

The replacement of cement with ***MetaMax***® High Reactivity Metakaolin did not reduce the workability of these concretes as measured by slump. In comparison with the concretes containing silica fume, the workability, based upon slump and consistency, of the concretes containing ***MetaMax*** was significantly better when equivalent superplasticizer additions were made. For the pre-cast producer, this can translate into more efficient filling of the forms and easier consolidation.

Hardened Concrete Properties

The 28 day compressive strength of the concretes was improved when the cement was replaced with the highly reactive pozzolans. The concretes containing ***MetaMax*** showed similar performance to the silica fume concretes. Because of the variability of the early age strength measurements, a precise conclusion cannot be reached. However, although cement was removed, the strength was not reduced, and, in some cases, was significantly improved. When accelerated curing was used, the concrete containing ***MetaMax*** showed higher compressive strengths at all testing ages.

ADDITIONAL COMMENTS

In this study, two single point replacements of Type I cement were made to existing pre-cast mixture designs. No optimization ladder was performed. When possible, each concrete formulation should be tested at several ***MetaMax*** replacements to determine the optimum cost versus performance level. For standard mixtures, the recommended starting point for strength enhancement is 7% by weight of cement. If chemical resistance is required, replacement rates of over 10% by weight ***MetaMax*** is recommended. For additional formulating suggestions, please call our engineering staff at (732) 205-5000 or fax us at (732) 205-5300.