

Benefits of MetaMax[®] High Reactivity Metakaolin: Addition vs. Replacement

Engelhard MetaMax metakaolin, a white, thermally activated aluminosilicate, is a highly reactive mineral admixture that enhances the performance of cement-based products, including mortars, grouts, shotcrete, and precast-prestressed and ready-mixed concrete. MetaMax metakaolin is a specially manufactured pozzolan that is produced in an ISO-9002 certified facility using statistical process quality control (SPQC) to produce a consistent and uniform product.

MetaMax High Reactivity Metakaolin (HRM) can be used on a replacement basis, by substituting for portland cement, or on an addition basis, by adding to the cementitious content of the existing formulation.

This study indicates that both an increase in compressive strength and a reduction of chloride ion permeability can be achieved when MetaMax is included. These benefits were seen when MetaMax was in the concrete formulation either as a replacement or as an addition. Comparison was made with silica fume to show the high pozzolanic activity of MetaMax.

Introduction:

This report summarizes a laboratory compressive strength and rapid chloride permeability study performed at a ready-mix plant laboratory and tested by an independent laboratory in Chicago, Illinois. The concrete mixtures studies were:

- high performance concrete formulation (control)
- An addition of 8% (based upon cement mass) MetaMax metakaolin
- An addition of 8% densified silica fume
- A replacement of 8% of the cement with MetaMax metakaolin, and
- A replacement of 8% of the cement with densified silica fume.

Concrete Mixture Proportions:

Table 1 lists the actual mixture proportions and fresh concrete properties for each concrete. The fine aggregate content was adjusted to maintain similar yields. Densified silica fume or MetaMax metakaolin was added with the cement in dry powder form. ASTM C-494 Type A water-reducer and Type F high-range water-reducer (superplasticizer) were used in each of the mixtures which were prepared in a 2 ft³ electric mixer.

Type F high-range water-reducer (superplasticizer) was adjusted to maintain similar workability (according to slump cone measurements and visual appearance). The MetaMax metakaolin required significantly less (27-50%) superplasticizer than the densified silica fume mixture to achieve comparable workability.

In these experimental formulations, no air entraining admixtures were added so a more direct determination of the effect of MetaMax metakaolin on strength versus the control and the silica fume mixtures could be made. Past studies have indicated that MetaMax containing concrete, in comparison to silica fume concrete, may require additional less air-entraining agent to achieve similar entrained air contents.

TABLE 1. MIXTURE PROPORTIONS (PER CUBIC YARD)

	Control Formulation	Addition of 8% MetaMax metakaolin	Addition of 8% Silica Fume	Replacement of 8% of cement with MetaMax metakaolin	Replacement of 8% of cement with Silica Fume
Type I cement (lb)	650	650	650	595	595
Fine Aggregate, SSD (lb)	1470	1410	1410	1470	1470
¾-in. Coarse Aggregate, SSD (lb)	1740	1740	1740	1740	1740
Densified Silica Fume (lb)	0	0	55	0	55
MetaMax Metakaolin (lb)	0	55	0	55	0
Water (lb)	260	260	260	260	260
Type A water reducer (oz.)	19.5	19.5	19.5	18.0	18.0
Type F High Range Water Reducer (oz.)	91	167	213	122	183
Slump (in.)	8½	10½	10	9¼	9¼
Temperature (°F)	68	71	71	69	71
Air (%)	2.3	3.0	3.1	2.8	3.5
Unit Weight (lb/ft ³)	151.2	152.0	150.4	150.4	148.8
Yield (ft ³ /yd ³)	27.2	27.1	27.4	27.4	27.7

Concrete Performance:

Compressive Strength Development

MetaMax metakaolin gave significantly higher compressive strength than the non-pozzolanic control formulation and a higher strength than the concrete containing silica fume. Compressive strength measurements were an average of two 4x8-inch cylinders that were continually moist-cured until the day of testing. Table 2 shows the compressive strength results.

TABLE 2. COMPRESSIVE STRENGTH RESULTS (ASTM C-39).

Testing Age (Days)	COMPRESSIVE STRENGTH (psi)				
	Control Formulation	Addition of 8% MetaMax metakaolin	Addition of 8% Silica Fume	Replacement of 8% of cement with MetaMax metakaolin	Replacement of 8% of cement with Silica Fume
7	8600	11600 (+35%)	10200 (+19%)	10600 (+23%)	9600 (+12%)
28	10000	13700 (+37%)	12900 (+28%)	12500 (+24%)	12200 (+22%)
56	11300	15200 (+34%)	14000 (+23%)	13700 (+21%)	13600 (+20%)
90	12200	16500 (+36%)	15800 (+30%)	16400 (+35%)	15300 (+26%)
180	13000	17300 (+33%)	16700 (+28%)	17300 (+33%)	16800 (+29%)
365	14100	18500 (+31%)	18000 (+27%)	18700 (+32%)	17500 (+24%)

() - numbers in parenthesis represent % strength increase over control formulation.

Rapid Chloride Permeability

The addition of MetaMax metakaolin or the replacement of cement with MetaMax decreased the rapid chloride permeability of the concrete when compared to the non-pozzolanic control formulation. The results of the MetaMax metakaolin concrete were comparable to those obtained using densified silica fume. Rapid chloride permeability testing was performed on the middle 2-inch section of two 4x8-inch cylinders. The cylinders were moist-cured for 56 days before the permeability measurements were taken. Table 3 shows the average coulombs passed after a six hour period for two specimens.

TABLE 3. RAPID CHLORIDE ION PERMEABILITY TEST RESULTS (AASHTO T-277-89).

	Control Formulation	Addition of 8% MetaMax metakaolin	Addition of 8% Silica Fume	Replacement of 8% of cement with MetaMax metakaolin	Replacement of 8% of cement with Silica Fume
Charge Passed, Coulombs	1800	900	600	1000	900

Conclusions:

This study shows that significant improvements in concrete strength and reduction in permeability can be achieved using MetaMax[®] high reactivity metakaolin. These improvements are observed when MetaMax metakaolin is used either in addition to, or in place of, portland cement in a given concrete formulation.

The MetaMax metakaolin required significantly less high range water reducer (superplasticizer) than silica fume to achieve equal workability as measured by the slump cone.

When MetaMax metakaolin is added to the concrete, the strength improved by over 30% versus the non-pozzolanic control. When the portland cement was replaced with the MetaMax, the compressive strength improvement is greater than 20% at 28 days. In this formulation, the compressive strength development of the MetaMax-containing concrete are slightly greater than those of the densified silica fume concrete.

The rapid chloride permeability of the MetaMax metakaolin concrete is lower than the original control formulation and comparable to the silica fume concrete.

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