Evaluation of Metakaolin For HPC Deck Overlays

Final Report
for
MLR-11-01

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Highway Division

Iowa Department Of Transportation

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8. ABSTRACT

The use of High Performance Concrete (HPC) in Iowa has consisted of achieving slightly higher compressive strengths with an emphasis on reduced permeability. Concrete with reduced permeability has increased durability by slowing moisture and chloride ingress. Achieving reduced permeability has typically been accomplished with combinations of slag and Class C fly ash, or the use of blended cements such as locally available Type IS(20), IS(25) and Type IP(25) in conjunction with Class C fly ash.

Fly ash has been used in the majority of concrete placed in Iowa since 1984 and slag has been available in Iowa since 1995. During the economic downturn in 2008, one of the cement plants that produced a Type IS(25) cement was forced to shut down, which reduced the availability of blended cements, typically used on HPC deck overlays.

Recently, a source of high reactivity metakaolin has been made available. Metakaolin is produced by heating a pure kaolinite clay to 650 to 700 °C in a rotary kiln (calcining). Metakaolin is a white pozzolan that is used to produce concrete with increased strengths, reduced permeability, reduced efflorescence, and resistance to alkali silica reactivity. The W.R. Grace MK-100 metakaolin will likely be available in dissolvable bags between 25 and 50 pounds. Thus, the mix designs were based on the anticipated bag size range for field use.

This research evaluated metakaolin mixes with and without Class C fly ash. Results indicated a seven percent replacement with metakaolin produced concrete with increased strengths and low permeability. When used with Class C fly ash, permeability is reduced to very low rating. Metakaolin may be used to enhance hardened concrete properties for use in high performance concrete (HPC).

9. KEY WORDS	10. NO. OF PAGES
Metakaolin, ASTM C666, Rapid chloride permeability	11

DISCLAIMER

The contents of this report reflect the views of the author(s) and do not necessarily reflect the official views or policy of the Iowa Department of Transportation. This report does not constitute a standard, specification or regulation.

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Introduction

The use of High Performance Concrete (HPC) in Iowa has consisted of achieving slightly higher compressive strengths with an emphasis on reduced permeability. Concrete with reduced permeability has increased durability by slowing moisture and chloride ingress. Achieving reduced permeability has typically been accomplished with combinations of slag and Class C fly ash, or the use of blended cements such as locally available Type IS(20), IS(25) and Type IP(25) in conjunction with Class C fly ash.

Fly ash has been used in the majority of concrete placed in Iowa since 1984. Slag has been available in Iowa since 1995. During the economic downturn in 2008, one of the cement plants that produced a Type IS(25) cement was forced to shut down, which reduced the availability of blended cements, typically used on HPC deck overlays.

Recently, a source of high reactivity metakaolin has been made available. Metakaolin is produced by heating a pure kaolinite clay to 650 to 700 °C in a rotary kiln (calcining). Metakaolin is a white pozzolan that is used to produce concrete with increased strengths, reduced permeability, reduced efflorescence, and resistance to alkali silica reactivity. The W.R. Grace MK-100 metakaolin will likely be available in dissolvable bags between 25 and 50 pounds. Thus, the mix designs were based on the anticipated bag size range for field use.

Objective

The objective of this research is to evaluate how metakaolin can be used to enhance hardened concrete properties for use in high performance concrete (HPC) without sacrificing placement and finishing characteristics. Hardened concrete properties such as strength, freeze thaw durability, and rapid chloride permeability will be investigated.

Materials and Mix Design

An HPC-O mix design was used for each mix batched. Table 1 lists the materials used in the laboratory mixes. A copy of each mix design may be found in the Appendix.
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Table 1 – Material Sources

Mix No.	Cement	Metakaolin MK-100	Fly ash	Air	Water Reducer
1	Lafarge I/II	0	0	Daravair 1400	Mira 62
2	Lafarge I/II	7.0% (50lbs)	0	Daravair 1400	Mira 62
3	Lafarge I/II	3.5% (25lbs)	Louisa 15%	Daravair 1400	Mira 62
4	Lafarge I/II	7.0% (50lbs)	Louisa 15%	Daravair 1400	Mira 62

Test Procedure

For each mix design samples were batched, cast and cured in accordance with ASTM C 192. A total of six cylinders were tested in accordance with ASTM C 39, three for 7 day strength and three for 28 day strength. An additional cylinder was cast from each mix for rapid indication of chloride permeability (2 samples) testing in accordance with ASTM C 1202. Samples for rapid chloride permeability testing were cured using the Virginia rapid curing of 7 days in moist room at 73 °F and then 21 days in a water bath at 100 °F. 3" X 4" x 16" durability specimens were also cast from each mix, cured for 14 days in the moist room, and subjected to freeze-thaw testing in accordance with ASTM C 666, Method A.

During finishing of the freeze thaw specimens, it was noted that the mixes with metakaolin were a little more sticky to finish, but not unmanageable. With the addition of fly ash, the concrete finished a little better. Any mix stickiness is something that the contractor should aware of during placement and take necessary precautions.

Results

The results of the plastic concrete mix properties as batched are found in Table 2.

Table 2 – ASTM C 666 Method B data

Mix No.	Air, *%*	Slump, *in.*	w/c
1	8.6	4	0.390
2	6.0	2	0.395
3	8.0	5	0.388
4	6.6	3	0.390

It should be noted that the higher slump for Mix 3 was likely due to the mid-range water reducer being introduced late in the mix cycle during the two minute remix.

Hardened concrete test results are found in Table 3. Freeze thaw test results of relative dynamic modulus and percent growth are plotted as shown in Figures 1 and 2.

Table 3 – Hardened Concrete Test Results

	Compressive strength, *psi*		Permeability		
Mix No.	7 day	28 day	Charge passed, *coulombs*	Rating	F/T Method A, *DF*
1	4640	5660	2638	Moderate	94
2	6140	7120	1074	Low	92
3	4910	6250	1559	Low	93
4	5720	7190	868	Very Low	93

Figure 1 – ASTM C 666 Method A, Relative Dynamic Modulus

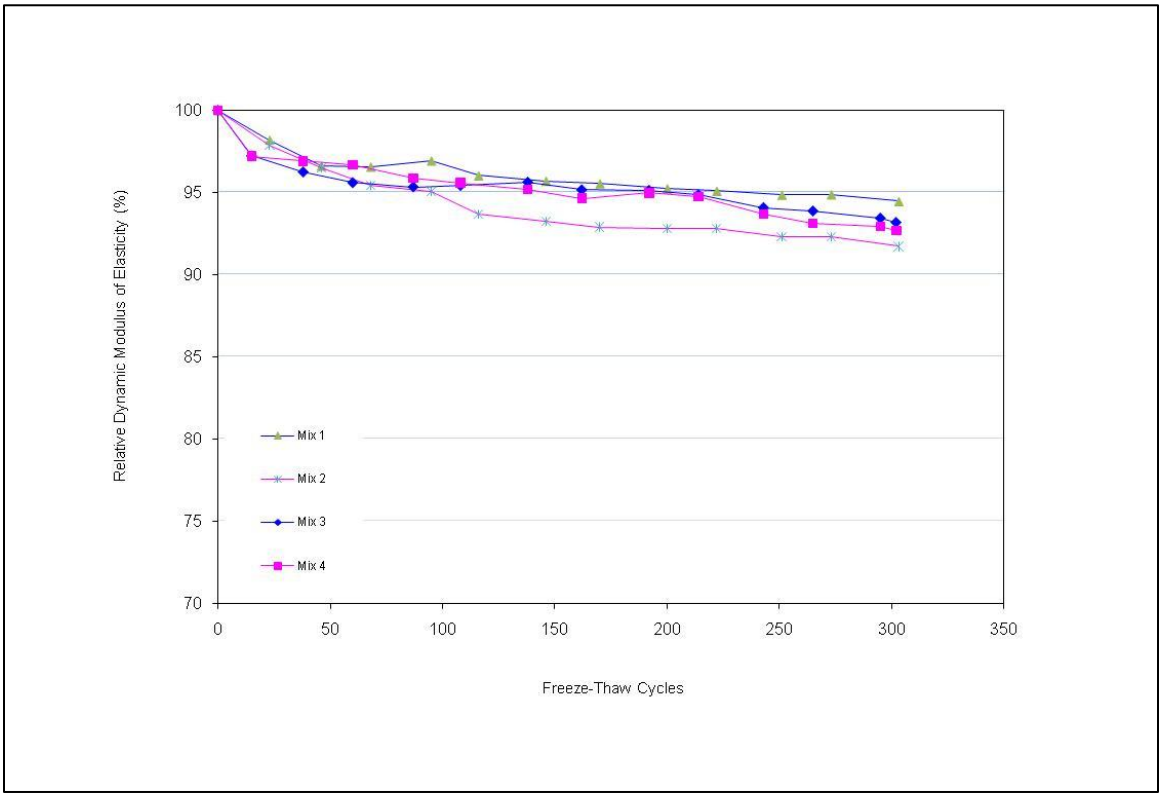
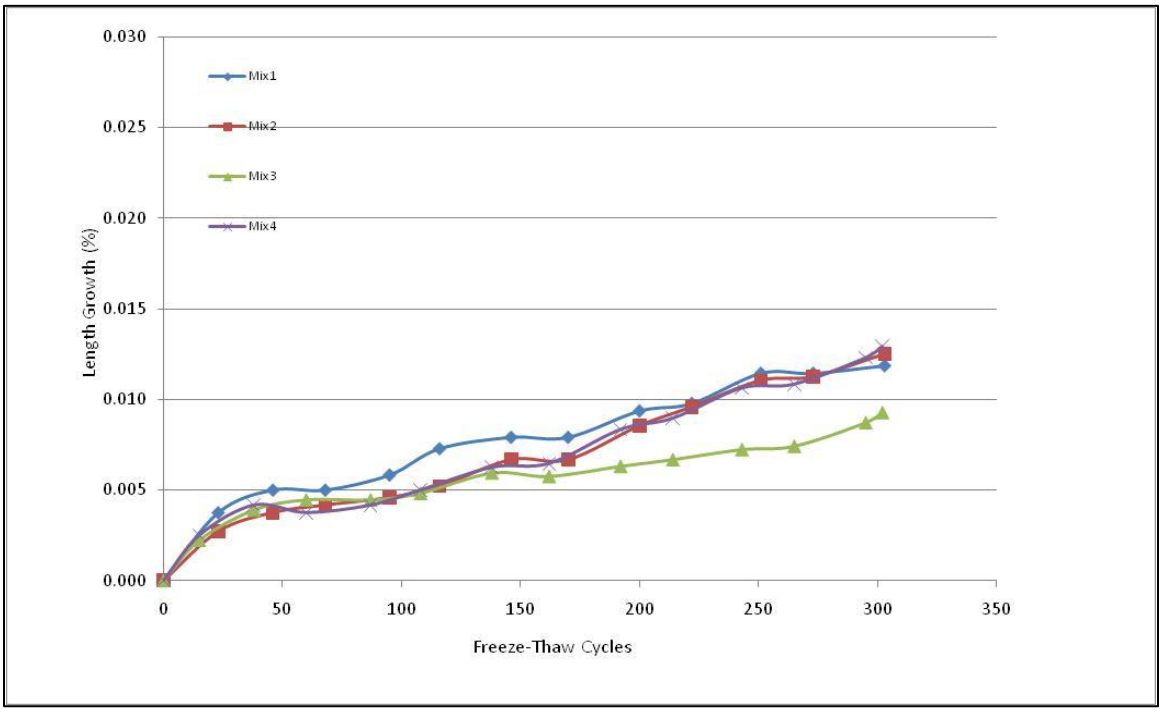


Figure 2 – ASTM C 666 Method A, Percent Growth



Discussion

Mix 2 and 4 with seven percent metakaolin replacement exhibited increased 7 day and 28 day compressive strengths over Mix 1 control. For mix 2 with three percent replacement, the 7 day compressive strength was slightly greater than the control strength however the 28 day compressive strength shows an increase over the control.

When tested by the rapid chloride permeability test, the indicated permeability was low for mix 2 and 3, although mix 2 was slightly higher. The indicated permeability was very low for mix 4 with seven percent metakaolin replacement and 15 percent fly ash replacement.

Freeze thaw durability was excellent for all mixes tested. Scaling was observed more prominently in the Mix 1 beams. There was relatively little scaling observed in Mix 4. Pictures of the freeze thaw durability beams after 300 cycles are shown in Figures 3 to 6.

Figure 3 – Freeze thaw beams – Mix 1

Figure 4 – Freeze thaw beams – Mix 2

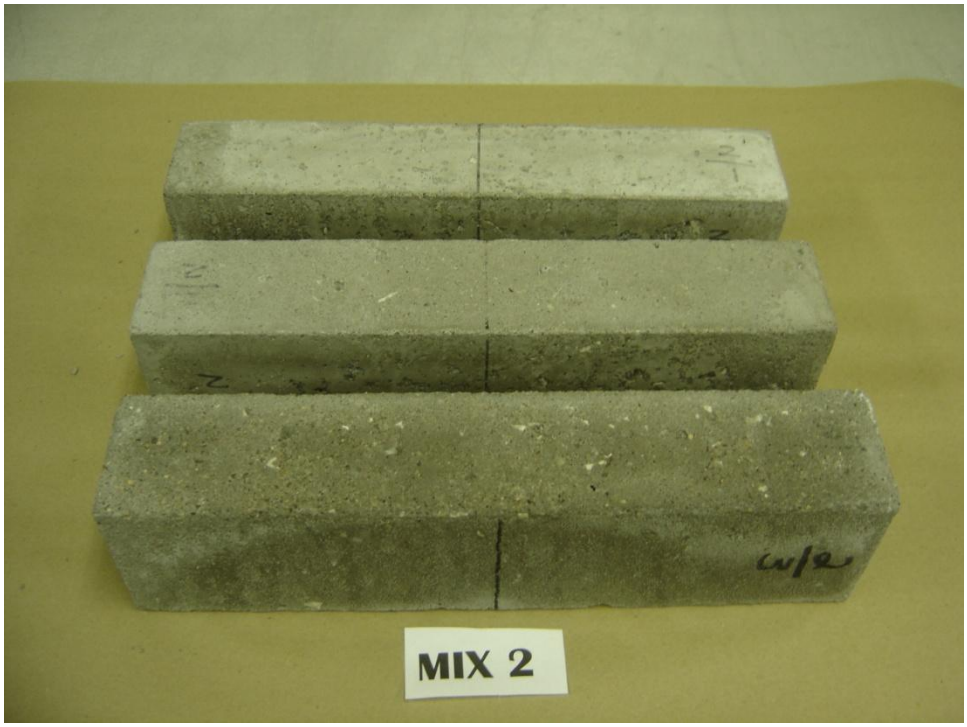
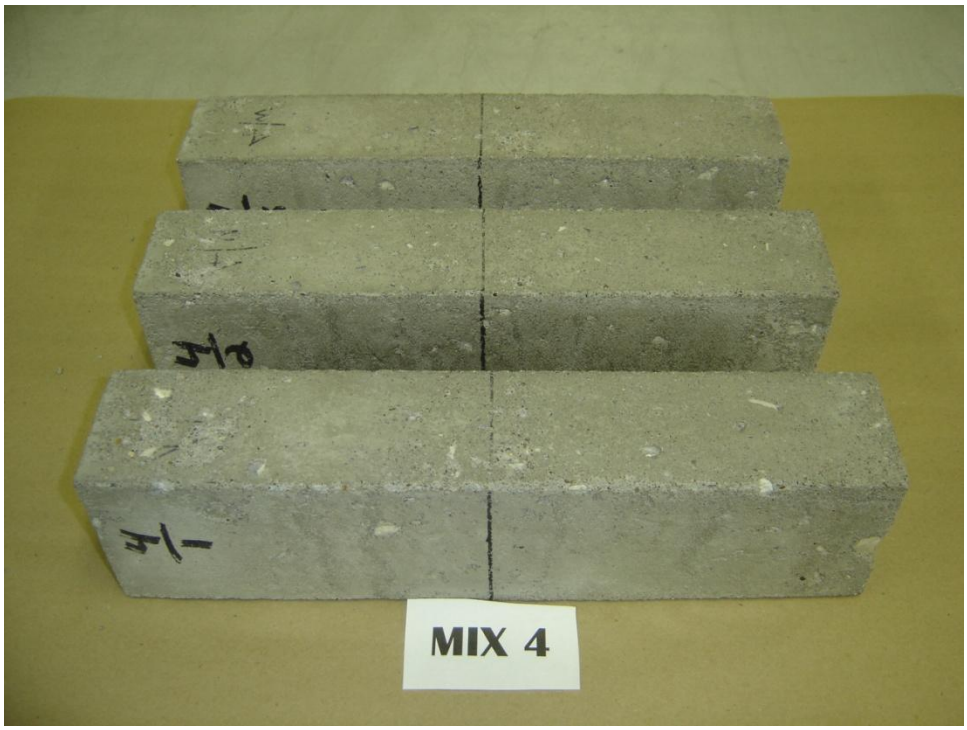


Figure 5 – Freeze thaw beams – Mix 3

Figure 6 – Freeze thaw beams – Mix 4



Conclusions and Recommendations

Based on the findings of this report, the following conclusions and recommendations:

- Mix 2 with 7 percent replacement with metakaolin produced concrete with increased 7 and 28 day compressive strengths over the control Mix 1 and Mix 3 with 3 percent replacement and 15 percent fly ash replacement. Permeability was low for both mixes.

- Mix 4 with 7 percent replacement with metakaolin and 15 percent fly ash replacement produced concrete with very low permeability and increased 7 and 28 day compressive strengths over the control Mix1 and Mix 3 with 3 percent replacement and 15 percent fly ash replacement .

- Recommend a field trial to determine placing and finishing characteristics.

Acknowledgement

The author would like to thank the Cement and Concrete section and Chengsheng Ouyang for their assistance in this research.

Appendix

Mix Design Mix 1

GENERAL INFORMATION											
PROJECT:	Metakaolin										
PROJECT TITLE:	0										
MIX TYPE:	HPC-O						***Paste Content***	30.2			
MIX NUMBER:	1						***Mortar Content (abs vol)***	68.1			
DATE:	6/23/2010						***Mortar Content (% pass)***	36.2			

MATERIALS	*Source*	*Type/Class*	*SPG*	*Percent*	*Percent*		*Abs. Vol.*
CEMENT:	Lafarge	I/II	3.14				0.134
FLY ASH:				0.00			0
MINERAL ADMIXTURE:				0.00			0
WATER (w/c ratio):		0.4	1.00				0.168
AIR CONTENT:		6.0					0.060
FINE AGGREGATE:	Prairie Du Chien		2.67	50.00			0.319
COARSE AGGREGATE:	Ft. Dodge		2.68	50.00			0.319
INTERMEDIATE AGGREGATE:	0		0	0.00			0
AIR ENTRAINING AGENT:	Daravair 1400					*Total*	1.000
RETARDER:						*Paste+Air*	0.362
WATER REDUCER:	Mira 62					*Agg*	0.638
SUPER WATER REDUCER:							
ACCELERATOR:							
DESIGN SLUMP:	4.0						

QUANTITIES (absolute volume method in SSD condition)

	Volume ft3 Batch Size 1.0 yd3	Volume ft3 Batch Size 1.0 ft3						Weight lbs Batch Size 1.0 ft3	Weight lbs Batch Size 1.0 yd3	Weight lbs Lab Batch Size 1.00
CEMENT:	0.134	3.62	X	3.14	X	62.4	=	26.3	709	26.3
FLY ASH:	0.000	0.00		0.00		0.0		0.0	0	0.0
MINERAL ADMIXTURE:	0.000	0.00		0.00		0.0		0.0	0	0
WATER:	0.168	4.54	X	1.00	X	62.4	=	10.5	283	10.5
FINE AGGREGATE:	0.319	8.61	X	2.67	X	62.4	=	53.1	1435	53.1
COARSE AGGREGATE:	0.319	8.61	X	2.68	X	62.4	=	53.3	1440	53.3
INTERMEDIATE AGGREGATE:	0.000	0.00	X	0.00	X	0.0	=	0.0	0	0.0
AIR:	0.060	1.62	X	0.00	X	62.4	=	0.0	0	0.0
Summation	**1.0000**	**27.00**						**143.2**	**3867**	**143.2**

CHEMICAL ADMIXTURES

	Rate oz/100 lbs cementitious							Rate (ml) Batch Size 1.0 ft3	Rate (ml) Batch Size 1.0 yd3	Rate (ml) Lab Batch Size 1.0
AIR ENTRAINING AGENT:	0.7	26.26	X	0.007	X	29.57	=	5.4	146.7	5.4
RETARDER:										
WATER REDUCER:	3.0	26.26	X	0.03	X	29.57	=	23.3	628.9	23.3
SUPER WATER REDUCER:										
ACCELERATOR:										

Mix Batch Weights		Ft. Dodge		0		Prairie Du Chien	
%	**Sieve**	**Coarse**		**Intermediate**		**Fine**	
		lbs	grams	lbs	grams	lbs	grams
10	3/4"	5.3	2420	0.0	0		
50	1/2"	26.7	12099	0.0	0		
25	3/8"	13.3	6050	0.0	0		
15	#4	8.0	3630	0.0	0		
	Total	53.3	24198	0.0	0	53.1	24108

Mix Design Mix 2

GENERAL INFORMATION											
PROJECT:	Metakaolin										
PROJECT TITLE:	0										
MIX TYPE:	HPC-O MK100					***Paste Content***		30.4			
MIX NUMBER:	2					***Mortar Content (abs vol)***		68.2			
DATE:	6/23/2010					***Mortar Content (% pass)***		36.4			

MATERIALS	*Source*	*Type/Class*	*SPG*	*Percent*	*Percent*		*Abs. Vol.*
CEMENT:	Lafarge	I/II	3.14				0.125
FLY ASH:				0.00			0
MINERAL ADMIXTURE:	W.R. Grace	MK-100	2.60	7.00			0.011
WATER (w/c ratio):		0.4	1.00				0.168
AIR CONTENT:		6.0					0.060
FINE AGGREGATE:	Prairie Du Chien		2.67	50.00			0.318
COARSE AGGREGATE:	Ft. Dodge		2.68	50.00			0.318
INTERMEDIATE AGGREGATE:	0		0	0.00			0
AIR ENTRAINING AGENT:	Daravair 1400					*Total*	1.000
RETARDER:						*Paste+Air*	0.364
WATER REDUCER:	Mira 62					*Agg*	0.636
SUPER WATER REDUCER:							
ACCELERATOR:							
DESIGN SLUMP:	4.0						

QUANTITIES (absolute volume method in SSD condition)

	Volume ft3 Batch Size 1.0 yd3	Volume ft3 Batch Size 1.0 ft3						Weight lbs Batch Size 1.0 ft3	Weight lbs Batch Size 1.0 yd3	Weight lbs Lab Batch Size 1.00
CEMENT:	0.125	3.38	X	3.14	X	62.4	=	24.4	659	24.4
FLY ASH:	0.000	0.00		0.00		0.0		0.0	0	0.0
MINERAL ADMIXTURE:	0.011	0.30	X	2.60	X	62.4	=	1.9	50	1.9
WATER:	0.168	4.54	X	1.00	X	62.4	=	10.5	283	10.5
FINE AGGREGATE:	0.318	8.59	X	2.67	X	62.4	=	53.0	1430	53.0
COARSE AGGREGATE:	0.318	8.59	X	2.68	X	62.4	=	53.2	1436	53.2
INTERMEDIATE AGGREGATE:	0.000	0.00	X	0.00	X	0.0	=	0.0	0	0.0
AIR:	0.060	1.62	X	0.00	X	62.4	=	0.0	0	0.0
Summation	**1.0000**	**27.00**						**142.9**	**3858**	**142.9**

CHEMICAL ADMIXTURES

	Rate oz/100 lbs cementitious							Rate (ml) Batch Size 1.0 ft3	Rate (ml) Batch Size 1.0 yd3	Rate (ml) Lab Batch Size 1.0
AIR ENTRAINING AGENT:	0.7	26.26	X	0.007	X	29.57	=	5.4	146.7	5.4
RETARDER:										
WATER REDUCER:	6.0	26.26	X	0.06	X	29.57	=	46.6	1257.7	46.6
SUPER WATER REDUCER:										
ACCELERATOR:										

Mix Batch Weights		Ft. Dodge		0		Prairie Du Chien	
%	**Sieve**	**Coarse**		**Intermediate**		**Fine**	
		lbs	grams	lbs	grams	lbs	grams
10	3/4"	5.3	2412	0.0	0		
50	1/2"	26.6	12061	0.0	0		
25	3/8"	13.3	6031	0.0	0		
15	#4	8.0	3618	0.0	0		
	Total	53.2	24122	0.0	0	53.0	24032

Mix Design Mix 3

GENERAL INFORMATION											
PROJECT:	Metakaolin										
PROJECT TITLE:	0										
MIX TYPE:	HPC-O MK100 25+ FA					***Paste Content***	30.7				
MIX NUMBER:	3					***Mortar Content (abs vol)***	68.3				
DATE:	6/23/2010					***Mortar Content (% pass)***	36.7				

MATERIALS	*Source*	*Type/Class*	*SPG*	*Percent*	*Percent*		*Abs. Vol.*
CEMENT:	Lafarge	I/II	3.14				0.109
FLY ASH:	Louisa	C	2.65	15.00			0.024
MINERAL ADMIXTURE:	W.R. Grace	MK-100	2.60	3.50			0.006
WATER (w/c ratio):		0.4	1.00				0.168
AIR CONTENT:		6.0					0.060
FINE AGGREGATE:	Prairie Du Chien		2.67	50.00			0.316
COARSE AGGREGATE:	Ft. Dodge		2.68	50.00			0.317
INTERMEDIATE AGGREGATE:	0		0	0.00			0
AIR ENTRAINING AGENT:	Daravair 1400					*Total*	1.000
RETARDER:						*Paste+Air*	0.367
WATER REDUCER:	Mira 62					*Agg*	0.633
SUPER WATER REDUCER:							
ACCELERATOR:							
DESIGN SLUMP:	4.0						

QUANTITIES (absolute volume method in SSD condition)

	Volume ft3 Batch Size 1.0 yd3	Volume ft3 Batch Size 1.0 ft3						Weight lbs Batch Size 1.0 ft3	Weight lbs Batch Size 1.0 yd3	Weight lbs Lab Batch Size 1.00
CEMENT:	0.109	2.94	X	3.14	X	62.4	=	21.4	578	21.4
FLY ASH:	0.024	0.65	X	2.65	X	62.4	=	3.9	106	3.9
MINERAL ADMIXTURE:	0.006	0.16	X	2.60	X	62.4	=	0.9	25	0.9
WATER:	0.168	4.54	X	1.00	X	62.4	=	10.5	283	10.5
FINE AGGREGATE:	0.316	8.53	X	2.67	X	62.4	=	52.6	1421	52.6
COARSE AGGREGATE:	0.317	8.56	X	2.68	X	62.4	=	53.0	1431	53.0
INTERMEDIATE AGGREGATE:	0.000	0.00	X	0.00	X	0.0	=	0.0	0	0.0
AIR:	0.060	1.62	X	0.00	X	62.4	=	0.0	0	0.0
Summation	**1.0000**	**27.00**						**142.4**	**3845**	**142.4**

CHEMICAL ADMIXTURES

	Rate oz/100 lbs cementitious							Rate (ml) Batch Size 1.0 ft3	Rate (ml) Batch Size 1.0 yd3	Rate (ml) Lab Batch Size 1.0
AIR ENTRAINING AGENT:	0.7	26.26	X	0.007	X	29.57	=	5.4	146.7	5.4
RETARDER:										
WATER REDUCER:	6.0	26.26	X	0.06	X	29.57	=	46.6	1257.7	46.6
SUPER WATER REDUCER:										
ACCELERATOR:										

Mix Batch Weights		Ft. Dodge		0		Prairie Du Chien	
%	**Sieve**	**Coarse**		**Intermediate**		**Fine**	
		lbs	grams	lbs	grams	lbs	grams
10	3/4"	5.3	2405	0.0	0		
50	1/2"	26.5	12023	0.0	0		
25	3/8"	13.3	6012	0.0	0		
15	#4	8.0	3607	0.0	0		
	Total	53.0	24046	0.0	0	52.6	23881

Mix Design Mix 4

GENERAL INFORMATION											
PROJECT:	Metakaolin										
PROJECT TITLE:	0										
MIX TYPE:	HPC-O MK100+ FA					***Paste Content***	30.8				
MIX NUMBER:	4					***Mortar Content (abs vol)***	68.4				
DATE:	6/23/2010					***Mortar Content (% pass)***	36.8				
MATERIALS	*Source*	*Type/Class*	*SPG*	*Percent*	*Percent*		*Abs. Vol.*				
CEMENT:	Lafarge	I/II	3.14				0.105				
FLY ASH:	Louisa	C	2.65	15.00			0.024				
MINERAL ADMIXTURE:	W.R. Grace	MK-100	2.60	7.00			0.011				
WATER (w/c ratio):		0.4	1.00				0.168				
AIR CONTENT:		6.0					0.060				
FINE AGGREGATE:	Prairie Du Chien		2.67	50.00			0.316				
COARSE AGGREGATE:	Ft. Dodge		2.68	50.00			0.316				
INTERMEDIATE AGGREGATE:	0		0	0.00			0				
AIR ENTRAINING AGENT:	Daravair 1400					*Total*	1.000				
RETARDER:						*Paste+Air*	0.368				
WATER REDUCER:	Mira 62					*Agg*	0.632				
SUPER WATER REDUCER:											
ACCELERATOR:											
DESIGN SLUMP:	4.0										
QUANTITIES (absolute volume method in SSD condition)											
	Volume ft3 Batch Size 1.0 yd3	Volume ft3 Batch Size 1.0 ft3							Weight lbs Batch Size 1.0 ft3	Weight lbs Batch Size 1.0 yd3	Weight lbs Lab Batch Size 1.00
CEMENT:	0.105	2.84	X	3.14	X	62.4	=		20.5	553	20.5
FLY ASH:	0.024	0.65	X	2.65	X	62.4	=		3.9	106	3.9
MINERAL ADMIXTURE:	0.011	0.30	X	2.60	X	62.4	=		1.9	50	1.9
WATER:	0.168	4.54	X	1.00	X	62.4	=		10.5	283	10.5
FINE AGGREGATE:	0.316	8.53	X	2.67	X	62.4	=		52.6	1421	52.6
COARSE AGGREGATE:	0.316	8.53	X	2.68	X	62.4	=		52.8	1427	52.8
INTERMEDIATE AGGREGATE:	0.000	0.00	X	0.00	X	0.0	=		0.0	0	0.0
AIR:	0.060	1.62	X	0.00	X	62.4	=		0.0	0	0.0
Summation	**1.0000**	**27.00**							**142.2**	**3840**	**142.2**
CHEMICAL ADMIXTURES											
	Rate oz/100 lbs cementitious								Rate (ml) Batch Size 1.0 ft3	Rate (ml) Batch Size 1.0 yd3	Rate (ml) Lab Batch Size 1.0
AIR ENTRAINING AGENT:	0.7	26.26	X	0.007	X	29.57	=		5.4	146.7	5.4
RETARDER:											
WATER REDUCER:	6.0	26.26	X	0.06	X	29.57	=		46.6	1257.7	46.6
SUPER WATER REDUCER:											
ACCELERATOR:											

Mix Batch Weights		Ft. Dodge		0		Prairie Du Chien	
%	**Sieve**	**Coarse**		**Intermediate**		**Fine**	
		lbs	grams	lbs	grams	lbs	grams
10	3/4"	5.3	2397	0.0	0		
50	1/2"	26.4	11985	0.0	0		
25	3/8"	13.2	5993	0.0	0		
15	#4	7.9	3596	0.0	0		
	Total	52.8	23971	0.0	0	52.6	23881