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Evaluation of Silica Fume in Bridge Deck Concrete Overlays

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16 Abstract

Chlorides that are used for ice control on the Kansas highways cause serious corrosion of the reinforcing steel in concrete bridges. The Kansas Department of Transportation (KDOT) has tried various methods to prevent chloride from penetrating the concrete on bridge decks. In 1990 two silica fume bridge deck overlays were placed on I-470 in Shawnee County along side of two control bridges. While the silica fume overlays have successfully inhibited the chloride penetration of the concrete, extensive cracking occurred in the silica fume overlays. Most of the cracking occurred in the first five years of the bridge deck life. KDOT has made significant changes in curing methods since 1990 to control the early cracking in the silica fume overlays.

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Final Report

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ABSTRACT

The Kansas Department of Transportation (KDOT) has tried various methods to prevent chloride from penetrating the concrete on bridge decks. The chlorides are used for ice control on the Kansas highways and cause serious corrosion of the reinforcing steel in the bridges. In 1990 two silica fume bridge deck overlays were placed on I-470 in Shawnee County along side of two control bridges. Silica fume has successfully inhibited the chloride penetration of the concrete. Extensive cracking occurred on the silica fume overlays. Most of the cracking occurred in the first five years of the bridge deck life. KDOT has made significant changes in curing methods since 1990 to control the early cracking in the silica fume overlays

EVALUATION OF SILICA FUME IN BRIDGE DECK CONCRETE OVERLAYS

The use of deicers containing chloride on Kansas highways has long caused deterioration problems on Kansas bridge decks. Most of the deterioration was attributed to corrosion of the reinforcing steel caused by chloride penetrating the concrete. In the mid 1970's many states began using epoxy coated reinforcing steel to delay this corrosion. In the late 1980's silica fume was introduced to concrete mixes to improve the compressive strength and decrease the chloride permeability. Kansas' first use of silica fume on a concrete bridge deck was in 1990. Kansas had developed a dense overlay mix design that was used to control permeability for nearly 30 years prior to the use of silica fume in concrete.

Four new bridges were built on I-470 in Shawnee County near the Fairlawn and 29th Street intersection. A 2-1/2" bridge deck wearing surface with 5% silica fume was placed on one of the bridges (bridge number 3.50). A 2-1/2" bridge deck wearing surface with 7-1/2% silica fume was placed on a second bridge (bridge number 3.34). The other two bridges had Kansas dense overlays and were used as control bridges (bridge numbers 3.35 and 3.49). All bridges had 625 lbs of cementitious materials.

Compressive strength and permeability (AASHTO T-277) testing was conducted in 1990 when the bridges were built. Crack surveys were conducted annually from 1990 through 2005. The Geology Section of KDOT's Geotechnical Unit issued Bridge Deck Condition Reports for these four bridges in 2005. The bridges were overlaid with a Polymer Concrete (Two Coat Broom and Seed) in 2006. Relevant information from the 1990 tests, the final crack survey, and the Bridge Deck Condition Report are in Table 1. The results of the annual crack surveys are presented in Tables 2 through 6.

Table 1

		1990 Data		2006 Data		
Bridge Number	% Silica Fume	Compressive Strength psi	Perms AASHTO T-277 Coulombs	Total Cracking mm/ sq m	% Chlorides above Threshold	Mean Chlorides kg/cu m
3.35	0	6670	1793	1108	100	5.05
3.49	0	6410	3129	990	83.3	4.29
3.5	5	6240	567	1449	73.3	3.26
3.34	7.5	7060	306	1167	40	2.58

Table 2

Bridge Number	3.35	3.49	3.5	3.34
% Sil. Fume >	0	0	5	7.5
Year	Percent Delamination			
1990	0.06	0	0	0.04
1991	0.29	0	0.19	0.5
1992	0.43	0	0.19	0.58
1993	0.6	0	0.25	0.61
1994	0.69	0.07	0.44	0.68
1995	0.88	0.07	0.59	0.81
1996	0.91	0.09	0.59	0.89
1997	1.05	0.09	0.73	0.89
1998	1.05	0.09	0.8	0.95
1999	1.05	0.15	0.8	0.95
2000	1.13	0.15	0.8	1.06
2001	1.13	0.15	0.83	1.08
2002	1.28	0.15	0.88	1.15
2003	1.28	0.15	0.91	1.15
2004	1.43	0.2	1.01	1.13
2005	1.44	0.2	1.04	1.13

Table 3

Bridge Number	3.35	3.49	3.5	3.34
% Sil. Fume >	0	0	5	7.5
Year	Long. Cracking mm/sq m			
1990	30	0	0	0
1991	66	44	19	1
1992	68	60	25	1
1993	74	66	57	7
1994	74	70	60	7
1995	76	96	60	8
1996	77	116	60	18
1997	77	118	64	22
1998	81	134	79	28
1999	82	137	82	30
2000	82	137	82	33
2001	82	139	88	33
2002	88	144	96	41
2003	88	159	98	41
2004	90	159	98	41
2005	90	159	98	43

Table 4

Bridge Number	3.35	3.49	3.5	3.34
% Sil. Fume >	0	0	5	7.5
Year	Trans. Cracking mm/sq m			
1990	77	0	11	5
1991	276	38	150	55
1992	342	46	536	109
1993	440	235	793	388
1994	448	239	831	405
1995	470	371	834	522
1996	488	376	834	563
1997	508	410	848	580
1998	643	550	1056	830
1999	667	566	1072	856
2000	685	588	1074	894
2001	698	607	1088	896
2002	826	667	1124	910
2003	837	667	1140	924
2004	840	681	1143	935
2005	840	683	1143	944

Table 5

Bridge Number	3.35	3.49	3.5	3.34
% Sil. Fume >	0	0	5	7.5
Year	Skew. Cracking mm/sq m			
1990	52	0	38	46
1991	115	41	109	90
1992	118	55	161	107
1993	128	101	172	126
1994	131	101	175	131
1995	137	104	178	139
1996	137	112	178	142
1997	150	118	180	146
1998	168	131	200	168
1999	168	137	200	168
2000	168	137	200	175
2001	168	139	202	175
2002	178	144	208	180
2003	178	148	208	180
2004	178	148	208	180
2005	178	148	208	180

Table 6

Bridge Number	3.35	3.49	3.5	3.34
% Sil. Fume >	0	0	5	7.5
Year	Total Cracking mm/sq m			
1990	159	0	49	51
1991	457	123	278	146
1992	528	161	722	217
1993	642	402	1022	521
1994	653	410	1066	543
1995	683	571	1072	669
1996	702	604	1072	723
1997	735	646	1092	748
1998	892	815	1335	1026
1999	917	840	1354	1054
2000	935	862	1356	1102
2001	948	885	1378	1104
2002	1092	955	1428	1131
2003	1103	974	1446	1145
2004	1108	988	1449	1156
2005	1108	990	1449	1167

The threshold amount of chloride for salt induced corrosion is 0.60 kg per cubic meter. All four bridges had mean chloride levels well above the threshold value, however, the 7.5% silica fume bridge deck had chloride levels below the threshold value in 60% of the samples collected. None of the samples taken at a depth between 40 mm and 60 mm had chloride levels above the threshold values. The mean chloride concentration at this level for this bridge deck was 0.12 kg/cu meter.

The increase in chloride concentration is attributed to the density of the cracking in each bridge deck. The silica fume appears to have slowed the penetration of the chloride despite the crack density in these bridges. The 7.5% silica fume appears to be the most effective. Figure 1 shows a graph of the total crack densities in mm per square meter for each of the bridges. The two silica fume bridge decks had the most cracking with the 5% silica fume bridge deck having nearly 25% more cracking than the 7.5% silica fume bridge deck. The higher crack density in the 5% silica fume bridge deck may have lead to the higher chloride concentration verses the 7.5% silica fume bridge deck.

The two control bridges had lower crack densities but higher Rapid Chloride Permeabilites as measured by AASHTO T-277; therefore, they had the highest chloride concentrations of the 4 bridges. The crack density appears to be the controlling factor for the chloride concentration. Bridge 3.49 had a higher initial chloride permeability, but a lower crack density than bridge 3.35. The higher crack density in bridge 3.35 has contributed to the higher chloride concentration.

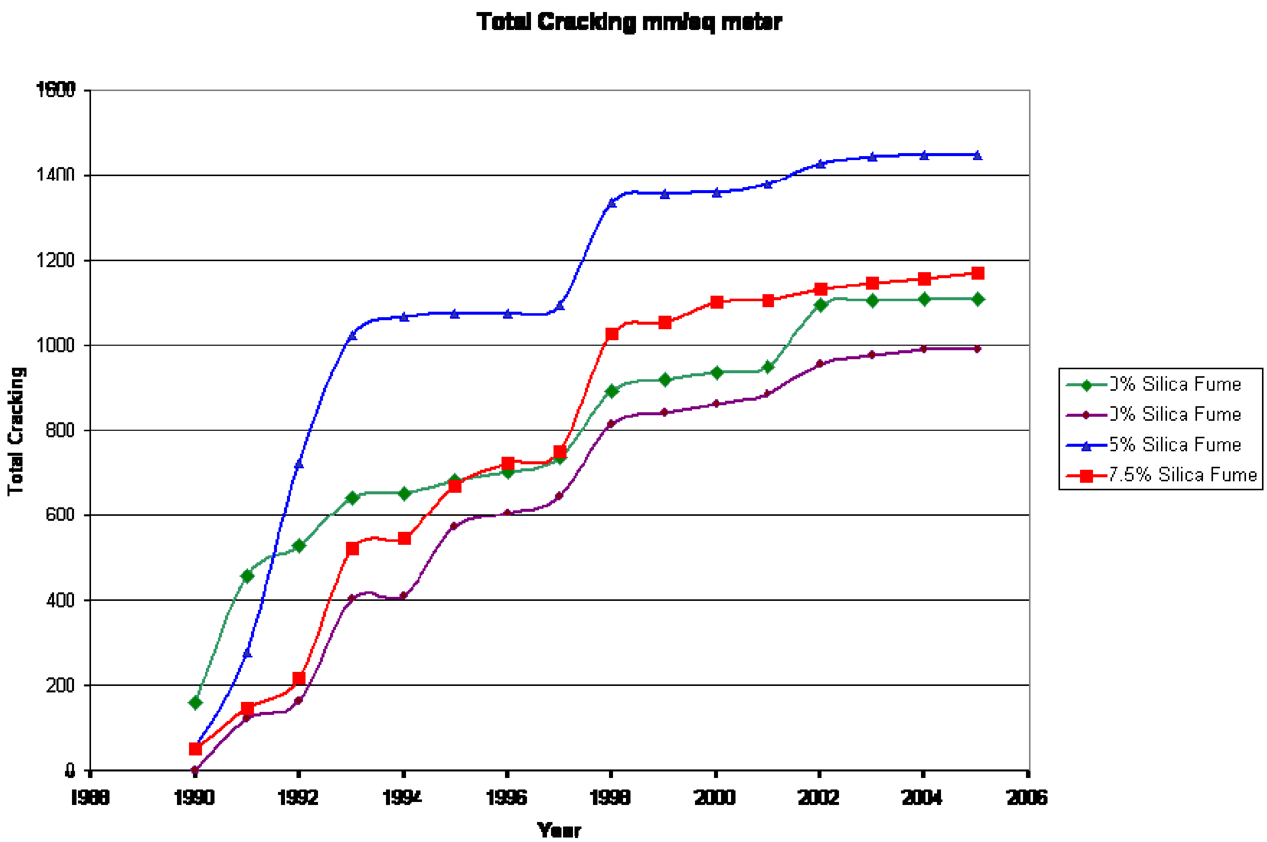

Figure 1

Silica fume is effective in controlling the penetration of the chlorides used for ice control on Kansas highways. Higher crack densities contribute to the overall chloride penetration. Nearly 60% of all the cracks developed in the first 5 years of the 16 year service life for these bridge decks. Fewer than 20% of the cracks developed over the last 8 years (1/2) of the service life. KDOT has made significant changes to specifications for silica fume overlays in an effort to control the early cracking in the concrete. These bridges were cured with wet burlap for a period of 72 hours. Current KDOT specifications require the application of Type 1-D liquid membrane forming compounds immediately behind the tining float. The concrete is then cured with wet burlap for a period of 7 days.

Darwin, Browning and Lindquist (2005) found that the age corrected crack density of the silica fume bridge decks in Kansas has been greatly reduced since the construction of these bridges. The mean crack density was 870 mm per square meter for the silica fume overlays that were constructed during the 1990 and 1991 construction seasons and included in their analysis. The mean crack density of bridges constructed between 2000 and 2002 was 480 mm per square meter. These crack densities were corrected to factor out the increase in cracking that occurs over time. K-TRAN Report: KU-01-9 investigates several other factors that affect the chloride contents of Kansas' concrete bridge decks.

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