RESEARCH NOTES

Contract: 59A0535
Task Order: 939
June 2011

Validating the Durability of Corrosion Resistant Mineral Admixture Concrete

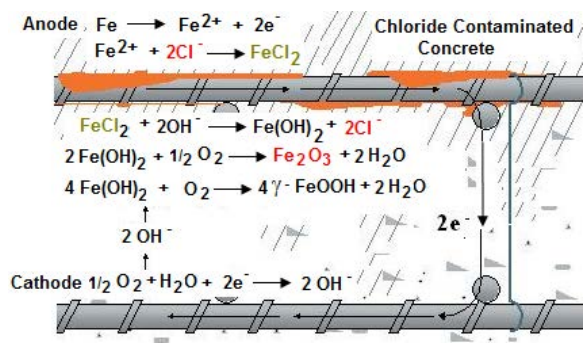
RESULTS: The accelerated chloride migration test of hardened concrete specimens found them to feature unusually low chloride diffusivity (D_s values in the order of 10^{-13} m^2/s vs. the commonly reported 10^{-12} m^2/s), corresponding to very high compressive strength. The chloride diffusivity in high-strength concretes was largely determined by the use of coarse aggregates whereas the effect of mineral admixtures was relatively small. All concrete mixes investigated had a 50%-probability service life of 114 years or longer (with a surface chloride concentration of 6 kg/m^3 and concrete cover of 50 mm), which highlights the great potential of reinforced concrete as a construction material when the concrete is made using the best practices of construction and curing and is free of cracking.

Background

In light of advances in concrete technology and requirements of the AASHTO Load and Resistance Factor Design (LRFD) for a 75-year design life, Caltrans made significant changes to its Bridge Design Specifications (BDS) Article 8.22 in 2000 and adopted the approach of using the chloride diffusivity through concrete to determine the concrete cover requirements for structures subjected to chloride-bearing environments. Like other state DOTs, Caltrans has developed concrete mixes for corrosion mitigation of structures with the aid of supplementary cementitious materials (SCMs). However, the work to date has been based on diffusion coefficient data for low permeability, mineral admixture concretes selected from available literature, which may not represent the materials and exposure conditions seen in California. Furthermore, a significant amount of variability exists in determining chloride diffusion coefficients as an indicator of concrete durability.

Why We Pursued This Research

Prior to this work, Caltrans saw the need for research to validate the corrosion mitigation design assumptions in order to better define the strategies used to design concrete structures with adequate corrosion mitigation measures and thus a "maintenance-free" service life. Additional research was also considered necessary to establish standard, reliable, and rapid test methods for determining chloride diffusion coefficients and chloride thresholds.



What We Did

Laboratory tests were conducted to investigate the compressive strength of and chloride diffusivity in mortar and concrete samples with cement partially replaced by various minerals (class F and class N fly ash [FA], ultra-fine fly ash [UFFA], silica fume [SF], metakaolin [MK] and ground granulated blast-furnace slag [GGBFS]), the porosity of mineral concretes, the freeze-thaw resistance of mineral mortars in the presence of deicers, and the effect of SCMs on the chloride binding and chemistry of the pore solution in mortar. A modified Accelerated Chloride Migration Test (ACMT) was developed for testing the chloride diffusivity in high quality concrete. A 2-D finite element method (FEM) based model, coupled with the stochastic technique, was developed to study the service life of reinforced concrete as a function of various influential factors.

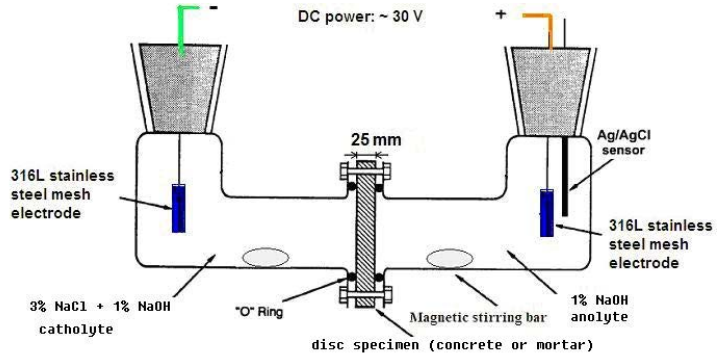
Research Results

- The combined addition of class F and MK dramatically reduced the 7-day compressive strength of mortar samples, followed by the use of GGBFS or SF, whereas the addition of most other minerals (except MK) also decreased the 7-day strength to various degrees. The combined addition of class F and MK increased the 28-day compressive strength of mortar samples, whereas the addition of most other minerals (except GGBFS) decreased the 28-day strength to various degrees. Mix design 9 (20% class F FA + 5% MK) and mix design 11 (10% SF) had the lowest binding capacity, whereas mix designs 1 (100% cement), 7 (10% UFFA) and 9 (50% GGBFS) had generally high chloride binding capacity relative to other mixes. All the mineral admixtures reduced the alkalinity of the pore solution in the mortar samples, regardless of their type and amount.

- The effect of partially replacing cement with SCMs on the steady-state diffusion coefficient (D_s) obtained from the ACMT was evaluated using 90-day old mortar samples. The results indicate that the use of 20% class F FA and 5% SF as cement replacement significantly increased the chloride diffusivity in mortar and the use of 10% MK or 50% GGBFS significantly decreased it, whereas other SCMs decreased the D_s to various degrees.

- The compressive strength of air-entrained concrete was consistently lower than that of their non-air-entrained counterpart, yet the differences in their chloride diffusivity were not as appreciable. All concrete specimens featured unusually low chloride diffusivity (D_s values in the order of 10^{-13} m^2/s), corresponding to very high compressive strength.

- The weight loss of mortar specimens was the greatest in the presence of diluted NaCl solution, followed by the diluted $CaCl_2$, and then by the diluted $MgCl_2$ solution, whereas the mortar deterioration in the de-ionized water was negligible. The partial replacement of cement by 50% GGBFS is most beneficial for the freeze-thaw resistance of mortar, followed by the 10% UFFA or 10% MK replacement; whereas the use of ordinary fly ash and silica fume seems to undermine the freeze-thaw resistance of mortar in the presence of various diluted chloride solutions.



- The technique developed in this work (e.g., multi-species transport model) was found to be very effective in predicting chloride migration and generating statistical conclusions about the service life of reinforced concrete. All concrete mixes investigated had a 50%-probability service life of 114 years or longer (with a surface chloride concentration of 6 kg/m^3 and concrete cover of 50 mm).

Mix No.	Mineral Admixtures	*Mortar*				*Non-Air-Entrained Concrete*				*Air-Entrained Concrete*			
		Average Compressive Strength (psi)			90-day ACMT	Properties			360-day ACMT	Properties			360-day ACMT
		1d	7d	28d	D_s (10^{-11} m^2/s)	Coarse-aggregate-to-cm ratio	Coarse-to-fine ratio	90 d compressive strength (psi)	D_s (10^{-13} m^2/s)	Coarse-aggregate-to-cm ratio	Coarse-to-fine ratio	90 d compressive strength (psi)	D_s (10^{-13} m^2/s)
1 & 2	None	904	3863	5105	1.77	2.17	1.53	10367	2.50	2.66	1.54	7834	2.74
3 & 4	FA F	752	3035	4025	1.50	2.80	1.51	9404	2.36	2.57	1.51	5654	3.77
5 & 6	FA N	934	2900	4204	1.55	NA	NA	NA	NA	NA	NA	NA	NA
7 & 8	FA F + SF	613	3480	4435	2.98	2.86	1.54	10020	2.99	2.59	1.52	5841	3.25
9 & 10	FA F + MK	690	1439	5613	1.28	2.85	1.53	9557	3.27	2.62	1.54	6833	3.14
11 & 12	SF	1056	2491	4859	1.30	2.79	1.51	9848	3.80	2.55	1.51	7869	3.96
13 & 14	MK	1106	3850	4675	0.84	2.80	1.51	11623	2.90	2.57	1.51	7070	3.70
15 & 16	UFFA	992	2887	4726	1.43	2.84	1.54	10335	3.71	2.60	1.54	6476	3.77
17 & 18	GGBFS	950	2148	5109	1.09	2.80	1.52	8560	3.52	2.57	1.52	5544	2.35

Recommendations

- The ACMT should be considered by the Caltrans corrosion technology branch for implementation, as it is anticipated to help Caltrans to make the transition from prescriptive specifications of concrete mixes to more performance-based specifications, which then would allow more innovation and flexibility in the materials selection of concrete and likely facilitate the paradigm shift from conventional PCC to environmentally friendly concretes.

- Caltrans should consider additional research phases for this work, such as the development and field evaluation of various types of high performance corrosion-resistant concretes. The research findings from such work should be shared with the DOT Design Engineers, as it may lead to improvements to the current Bridge Design Specifications in mitigating chloride-induced corrosion and deterioration. Continued research is needed to explore the effect of partially replacing cement with mineral admixtures on the durability of concrete.

- The role of coarse aggregates in concrete durability should be further explored. The processes and procedures used in the new construction should be closely supervised under a systematic quality assurance program, in order to achieve the great potential of reinforced concrete as a construction material and to manage corrosion risks pro-actively.

Reference

Xianming Shi, Yajunn Liu, Zhengxian Yang, Michael Berry, Prathish Rajaraman: "Validating the Durability of Corrosion Resistant Mineral Admixture Conrete", Final Report, December 30, 2010.

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