calcium nitrite, the reinforcing steel showed moderate severe to severe corrosion, and ranged in length from 2.0 to 15 in.. Moderate severe to very severe corrosion was observed in reinforcing steel specimens from slabs containing calcium nitrite at 6 gal/ yd³ The length of corrosion was from 3.0 to 4.25 in.. The length of corrosion and the overall severity of corrosion are summarized in Table 3.

A chloride analysis was performed on a total of nine test specimens (three each from the control mix, calcium nitrite at 4 gal/ yd³ and the OCIA at 1 gal/ yd³ The chloride analysis shows that chloride levels were highest in the specimens containing 4 gal/yd³ of calcium nitrite, and lowest in specimens containing the OCIA. The OCIA was found to, "significantly hinder the infiltration of chloride into the concrete and along the bar (7)."

ASTM G-109 Test

The ASTM G-109 test procedure is similar to the Time to Corrosion test described previously. The major differences in the G-109 test procedure is the use of smaller specimens (11 x 6 x 4.5 in.), a higher cement content (600 lbs), a 3% salt solution, and a monthly drying cycle at a temperature of 73 F.

The ASTM G-109 test was originally designed to evaluate the effectiveness of concrete admixtures in inhibiting corrosion. However, because of significant variability in test data from different labs, the test method is currently being reviewed.

Prior to these recent developments, the OCIA was tested by Wiss, Janney, Elstner Associates, Inc., a leading independent corrosion laboratory. More than a year after the test had started, none of the specimens (the OCIA nor the control mix) had initiated corrosion.

Effect of The OCIA on Plastic Properties

The OCIA has very little effect on the plastic properties of concrete. In the following sections, test data obtained from a field evaluation are presented on set time, slump, air content, and temperature development of concrete containing the OCIA and those of a reference concrete. The mixture proportions used in this evaluation are presented in the following table. The OCIA was used at a dosage which is consistent with that recommended for corrosion inhibition.

Concrete Mixture Data (field evaluation)

		Reference	OCIA
Cement	(lbs/ yd³)	650	650
Fine aggregate	"	1249	1249
Coarse Aggregate	"	1800	1800
Water	"	260	260
Air Entrainer	(fl. oz/cwt)	1.4	1.4
HRWRA		10.0	12.0
Organic Corrosion Inhibitor		-----	.20
(% by wt. of cement)*			.40
w/c ratio		.40	6.5
Slump (in.)		7.0	5.7
Air (%)		6.2	147.5
Unit Weight	(lb./cu. ft)	145.1	72
Concrete Temperature (°F)		73	

* 1 oz./cwt. is equivalent to 0.01% by wt. of cement

Set Time

The effect of The OCIA on the setting time of concrete was evaluated at ambient temperatures of 50, 72, and 90 °F. Both initial and final set times were obtained at each temperature. The test data are shown graphically in Figures 2 and 3. The data indicates that The OCIA did not have a significant effect on initial set time at ambient temperatures of 72 and 90 degrees Fahrenheit. At an ambient temperature of 50 degrees Fahrenheit, The OCIA retarded the concrete slightly. However, the amount of retardation is less than that specified in ASTM C-494 for classification as a Type B, Retarding admixture.

Slump

The OCIA has no effect on concrete slump as shown in Figure 4.

Air Content

The addition of OCIA to a concrete mixture may require extended mixing or an increase in the amount of air-entraining admixture used, to achieve a given air content.

Temperature Development Profile

As shown in Figure 5, the OCIA will not affect the peak exotherm of temperature development profile of concrete. The data shown in this figure were obtained from thermocouples placed in the middle of insulated 1.0 cu. ft. wooden boxes filled with concrete. The boxes were insulated to simulate a mass concrete placement. The temperature development profiles are consistent with the set time data discussed above.

EFFECT OF OCIA ON HARDENED PROPERTIES

Air-void System Parameters

The effect of the OCIA on the air-void system parameters of concrete were extensively evaluated using truck-mixed and central-mixed concretes. Air-entraining admixtures were used in these evaluations at dosages ranging from 1.5 to 3.0 fl. oz/cwt The results of the air-void system analysis are summarized in the Table 4 for the truck-mixed and central-mixed concretes. The data show excellent correlation between the plastic and hardened air contents, indicating that the OCIA will not affect the stability of the air voids during the hardening process. The calculated spacing factors are less than or equal to the maximum value of 0.008 in. recommended by ACI or adequate freeze-thaw durability of concrete.

Abrasion Resistance

The effect of the OCIA on the abrasion resistance of concrete was determined in accordance with ASTM C 779, Procedure A. The test data, shown in Figure 5 indicate equal depths of wear for the reference and the OCIA treated concretes after 60 minutes of exposure to abrasion. This implies that the OCIA will not affect the resistance of concrete subjected to severe abrasion.

Freezing and Thawing Resistance

The effect of the OCIA on the freezing and thawing resistance of concrete was evaluated in accordance with ASTM C 666, Procedure A. After 300 freezing and thawing cycles, a durability factor of 96 percent was obtained for the concrete containing the OCIA relative to the reference. This excellent relative durability factor indicates that the OCIA will not affect the freezing and thawing resistance of concrete.

Compressive Strength

When used in combination with certain types of natural, rounded aggregate, the addition of The OCIA may result in a decrease of compressive strength. By reducing the w/c ratio, the compressive strength can be returned to the original level.

Sulfate Resistance

The OCIA will increase the sulfate resistance of concrete. Data obtained from an accelerated sulfate resistance test developed by the Bureau of Reclamation Figure 7 show that the expansion of test specimens for concrete containing the OCIA is only slightly less than that for the reference concrete, after 15 weeks of testing. However, after 48 weeks of testing, the OCIA-treated concrete showed significantly less expansion compared to the reference concrete. This can be attributed to a slower ingress of the sulfate solution into the OCIA-treated concrete matrix.

Concrete-Steel Bond Strength

The bond strength developed between concrete and steel is not affected by the OCIA. Test data obtained from an independent evaluation conducted at the university of Kansas and presented in Figure 8 show that, on the basis of equal compressive strength, there is no difference in bond strength between the reference and treated concretes, even at a dosage rate which is twice that recommended for corrosion inhibition.

Modulus of Elasticity

The effect of the OCIA on the modulus of elasticity of concrete was evaluated in accordance with ASTM C 469 using a computerized data acquisition system and a pair of extensometers. This test setup enabled the determination of the strain at peak load and the toughness of the concrete. The data obtained are presented in Figures 10 and 11. As shown in Figure 9, the modulus of elasticity of the concrete mixture treated with the OCIA was marginally higher than that of the reference mixture. The slight increase in elastic Modulus is, however, considered insignificant. Figures 10 and 11 indicate that strain at peak load and toughness of concrete are not affected by the use of the OCIA.

CONCLUSION

Organic Corrosion Inhibiting Admixtures (OCIA's) represent the latest generation in corrosion inhibitors. Building on existing technologies, organic corrosion inhibitors offer an effective, cost efficient method of controlling corrosion in steel reinforced concrete.

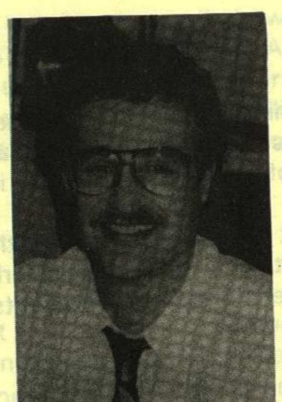
Results of extensive independent testing have shown this particular OCIA to be an extremely effective corrosion inhibiting system, particularly in delaying the onset of corrosion in cracked concrete where the aggressive agents have direct access to the reinforcing steel.

In evaluating the performance of this particular OCIA in uncracked and precracked time-to-corrosion tests, Wiss, Janney, Elstner Associates, Inc. concluded, "Concrete containing OCIA at 1 gal/ yd³, performed as well or better than concrete containing 2, 4, and 6 gal

of (calcium nitrite) in standard uncracked time-to-corrosion slab tests and precracked bea
tests (7)."

REFERENCES

1. "Our Nation's Highways- Selected Facts and Figures," U.S. Department of Transp tation, Federal Highway Administration, Office of Highway Information Manageme
2. Dunker, K.F., and Rabbat, B.G., "Why America's Bridges are Crumbling," Scienti American, March 1992, pp. 66-68 .
3. "Corrosion Basics, An Introduction," National Association of Corrosion Engine 1984, pp. 5.
4. Holland, T.C., "Corrosion Protection for Reinforced Concrete," Concrete Construc March 1992, pp. 230-236.
5. Nmai, C.K.; Farrington, S.A.; and Bobrowski, G.S., "Organic-Based Corrosio Inhibiting Admixture for Reinforced Concrete," Concrete International, April, 1992, 45-51.
6. RD-86/93, "Protective Systems for New Prestressed and Substructure Concre Federal Highway Administration, April, 1987, pp. 21.
7. Corrosion Testing of OCIA 222 for Master Builders, Inc., Wiss, Janney, Els Associates, 1993, pp. 1-19.



Will Secre, Marketing Manag for the Admixtures Division o Master Builders, Inc.

TABLE 1. Uncracked Beam Corrosion Test

Sample		Corrosion Current (uA)			Resistance (Ohms)		Half-cell Potential (-v)		
No.	**Description**	**1 wk**	**23 wk**	**48 wk**	**1 wk**	**48 wk**	**1 wk**	**23 wk**	**48 wk**
1A	Control	0	147	174	180	510	0.192	0.536	0.589
1B	Control	0	179	164	180	610	0.186	0.511	0.553
2A	2 gal CNI*	0	82	54	140	520	0.190	0.483	0.459
2B	2 gal CNI	0	56	253	150	420	0.176	0.400	0.589
3A	4 gal CNI	0	63	160	150	460	0.166	0.438	0.555
3B	4 gal CNI	0	1	6	150	530	0.186	0.180	0.308
4A	6 gal CNI	0	36	34	100	350	0.189	0.398	0.423
4B	6 gal CNI	0	0	0	120	460	0.194	0.219	0.165
5A	1 gal OCIA	0	9	6	200	930	0.187	0.314	0.330
5B	1 gal OCIA	0	0	0	200	840	0.199	0.161	0.163

* Calcium nitrite

TABLE 2. Uncracked Beam Corrosion Test- Rebar Condition

Sample No.	Length of Corrosion (in.)	Top/Bottom/ Circumference	Description
Control			
1A	9.0	T	Moderate to severe-deep pitting and flaking.
1A	5.0	T	Moderate to severe- deep pitting and flaking.
1B	3.25	T	Severe pitting
1B	5.0	T	Very severe, loss of rebar deformation
Calcium nitrite- 2 Gal/ yd³			
2A	4.0	T	Very severe pitting
2A	7.25	T	Moderate to severe
2B	6.25	T some on bottom	Moderate to severe
2B	6.75	T some on bottom	Moderate to severe
Calcium nitrite- 4 Gal/ yd³			
3A	4.75	T	Moderate to severe and very severe
3A	3.5	T	Moderate to severe
3B	0.25	T	Minor scale
3B	0.0	--	Very light scale
Calcium nitrite- 6 Gal/ yd³			
4A	2.5	T	Moderate to severe scale
4A	1.5	T	Moderate pitting
4B	0.25	T	Minor scale
4B	0.0	--	Very light scale
OCIA- 1 Gal/ yd³			
5A	4.0	T	Minor scale
5A	0.0	--	Very light scale
5B	0.0	--	Surface scale
5B	0.25	T	Very light scale

TABLE 3. Condition of Precracked Beam Specimens (Conclusion of Testing)

Specimen No.	Top Width of crack (in.)	Depth of crack (in.)	Maximum length of corrosion (in.)	Severity of corrosion	Location of corrosion (sides)
Control					
1A	0.005	3.50	7.00	Severe	Both
1B	0.009	3.00	8.00	Severe	Both
1C	0.009	2.75	8.00	Severe	Both
1D	0.009	3.50	10.00	Severe	Both
1E	0.007	3.25	11.00	Severe	Both
1F	0.009	3.50	9.00	Severe	Mostly one
1G	0.009	3.25	7.00	Severe	Both
1H	0.007	3.25	5.00	Severe	Mostly one
Calcium nitrite- 2 Gal/ yd³					
2A	0.010	2.75	14.00	Severe	Both
2B	0.005	3.00	14.00	Severe	Both
2C	0.005	3.25	14.50	Severe	Both
2D	0.007	3.00	8.00	Severe	One
2E	0.007	3.50	15.00	Severe	One
2F	0.009	3.50	15.00	Severe	One
2G	0.007	3.00	5.00	Severe	Mostly one
2H	0.005	3.25	5.00	Severe	Both
Calcium nitrite- 4 Gal/ yd³					
3A	0.010	3.25	14.00	Severe	Both
3B	0.011	3.50	14.50	Severe	One
3C	0.007	3.25	15.00	Severe	One
3D	0.009	3.00	11.00	Severe	One
3E	0.007	3.00	5.00	Severe	One
3F	0.007	3.75	3.50	Moderate severe	One
3G	0.007	3.50	3.00	Severe	Mostly one
3H	0.005	2.75	2.00	Severe	One
Calcium nitrite- 6 Gal/ yd³					
4A	0.007	3.00	11.00	Severe	Mostly one
4B	0.009	2.50	7.00	Severe	Both
4C	0.010	3.25	7.00	Very severe	Mostly one
4D	0.005	2.50	9.00	Severe	One
4E	0.005	3.00	4.00	Severe	One
4F	0.007	3.50	3.00	Severe	One