POLYMER MODIFIED CONCRETE STUDY

Final Report

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METRIC CONVERSION CHART

To convert U.S. Units to Metric Units (S.I.), the following conversion factors should be noted:

Multiply U.S. Units	By	To Obtain Metric Units
	LENGTH	
inches (in.)	2.5400	centimeters (cm.)
feet (ft.)	0.3048	meters (m.)
yards (yd.)	0.9144	meters (m.)
miles (mi.)	1.6090	kilometers (km.)
	AREA	
square inches (in^2)	6.4516	square centimeters (cm^2)
square feet (ft^2)	0.0929	square meters (m^2)
square yards (yd^2)	0.8361	square meters (m^2)
	VOLUME	
cubic inches (in^3)	16.3872	cubic centimeters (cm^3)
cubic feet (ft^3)	0.0283	cubic meters (m^3)
cubic feet (ft^3)	28.3162	liters (l.)
cubic yards (yd^3)	0.7646	cubic meters (m^3)
fluid ounces (fl. oz.)	29.57	milliliters (ml.)
gallons (gal.)	3.7853	liters (l.)
	MASS (WEIGHT)	
pounds (lb.)	0.4536	kilograms (kg.)
ounces (oz.)	28.3500	grams (g.)
	PRESSURE	
pounds per square inch (p.s.i.)	0.07030	kilograms per square centimeters (kg/cm^2)
pounds per square inch (p.s.i.)	0.006894	mega pascal (MPa)
	DENSITY	
pounds per cubic yard (lb/yd^3)	0.5933	kilograms per cubic meter (kg/m^3)
bags of cement per cubic yard (cement bags/yd^3)	55.7600	kilograms per cubic meter (kg/m^3)
	TEMPERATURE	
degrees fahrenheit (°F.)	5/9 (°F.-32)	degrees celsius (°C.) or centigrade

ABSTRACT

Four polymer modifiers, commercially known as: Dow SM Modifier "A", Thermoflex 8002, Arco-Dylex 1186, and Duralguard Modifier "E", were chosen to be evaluated in this study effort. The first three of these products were already approved by FHWA as alternates to low slump dense concrete known as Iowa Dense concrete, or epoxy coated reinforcing steel for bridge deck construction.

Primary concentration was on determining the effect these products had on reducing chloride penetration into the concrete.

The following general conclusions were made in this study:

1. Polymer modified concrete made with Thermoflex 8002, Arco-Dylex 1186, and Duralguard Modifier "E" all gave good strength results. Concrete made with Dow Modifier "A" gave strength somewhat lower but still near or above control mix.
2. All the specimen tested in this study showed good bond strength characteristics.
3. Good durability results were obtained on all the polymer modified concretes, except Dow Modifier "A" which showed moderate to severe scaling in the scaling resistance test.
4. All of the polymer modified concretes showed good results on the 90-day permeability test, except Duralguard Modifier "E".

The following recommendations are made:

1. Other polymer modifiers already on the FHWA approved list, should be accepted for use in the State of Louisiana as bridge deck overlay alternate bid items to the Iowa dense concrete
2. Duralguard Modifier "E" concrete is not recommended for use as bridge deck overlay for protection against chloride penetration.
3. Generally, since the polymer modified concretes lose their workability and slump rapidly, extra effort should be made to decrease application time during bridge deck overlay construction.

IMPLEMENTATION

Since the Federal Highway Administration has already approved the use of several polymer modified concretes (Dow Modifier "A", Thermoflex 8002, and Arco-Dylex 1186), the Department has allowed these products as alternates to the low slump dense concrete (LSDC), commonly referred to as Iowa Dense Concrete, on bridge deck overlays. This research study has generally reinforced previously obtained favorable results, but now evaluated under Louisiana conditions. No implementation is expected on the use of another product, Duralguard, Modifier "E", due to unfavorable 90-day chloride permeability test results.

New guidelines and procedures concerning the time of application of these materials and their use should be revised.

INTRODUCTION

Delamination is probably the most serious form of deterioration commonly found in bridge decks and reinforced pavements. It ultimately results in large scale spalling, necessitating costly repairs. This type of failure is believed to be caused chiefly from salt (sodium chloride) induced corrosion of the reinforcement. If the penetration of chloride can be reduced substantially, a significant increase in life of the bridge decks can be expected. One method of decreasing the chloride penetration is the use of polymer modifiers in portland cement concrete.

In recent years, the use of polymers in concrete has been investigated to improve the strength, durability and chloride resistance of concrete. There are different types of concretes and also polymer concretes, and different methods of producing these concretes. Some examples of the various types of concretes are as follows: Polymer-Impregnated Concrete; Polymer Concretes; Low Slump Dense Concrete (LSDC), commonly known as Iowa Dense Concrete; Internally-Sealed Concrete (Wax Bead); and Polymer Modified Concrete.

The Federal Highway Administration has approved the use of four polymer modifiers for concrete as alternates to low slump dense concrete (LSDC), known as Iowa Dense Concrete, and epoxy coated reinforcing steel for bridge decks. These products are as follows: Dow SM Modifier "A", Thermoflex 8002, Arco-Dylex 1186 and Deco Rez 4776. Deco-Rez 4776 is not a viable alternate, since it is no longer available.

The Louisiana Department of Transportation and Development introduced this research study to verify the results of the Federal Highway Administration when evaluated under Louisiana conditions. Since new products for the same purpose are always being introduced, another such product was considered for evaluation along with the three products approved by the FHWA. This product was Duralguard Modifier "E".

PURPOSE

The purpose of this research study was to determine and evaluate the properties of portland cement concrete using these presently approved polymer modifiers (Styrene Butadiene Latex Modifiers) when tested under Louisiana conditions; and also to determine and evaluate the properties of an additional product used for the same purpose, under a new product type evaluation, comparing it with the approved ones. Primary concentration was on determinimg the effect these products have on reducing chloride penetration into the concrete.

SCOPE

The scope of this research study included the following:

(1) to make concrete mixes (polymer modified and reference) in the laboratory for comparative purposes using a standard normally used concrete mix design.

(2) to conduct standard laboratory testing (strength and durability) and also conduct 90-day permeability testing (by FHWA procedures),

(3) to evaluate the results of the laboratory testing and made some comparisons of the strength, durability and resistance to chloride penetration of these various polymer modified concretes, and

(4) to make recommendations on the use of these polymer modified concretes in bridge deck overlays in this state.

METHOD OF PROCEDURE

The procedures involved in this research study included the addition of polymer modifiers to plastic concrete while mixing. These polymer modifiers were used only as additives to the regular concrete and not as replacements for any materials normally used in the mixing of concrete.

Mix designs were prepared using these polymer modifiers in the Portland Cement Concrete. There were five (5) different mix designs used for evaluation purposes. These were as follows: (1) control reference mix, (2) Dow Modifier "A" mix, (3) Thermoflex 8002 mix, (4) Arco-Dylex 1183 mix and (5) Duralguard Modifier "E" mix. All of the mixes had a cement content of 6.5 sacks cement per cubic yard, regular Class A gravel for the coarse aggregate, regular specification fine aggregate sand, a fine to coarse aggregate ratio of 40/60, and no other additives, such as air-entraining admixtures, in the mixes.

All of the polymer modifier materials were identified, sampled, fingerprinted and tested for latex solids content (see Attachment A, Appendix). There should have been a minimum of 46 percent of solids in the latex, according to the FHWA guidelines.

The mixing procedures on all of the design mixes were as follows: First, the total fine and coarse aggregates plus one third of the water were placed in the mixer and agitated for three minutes. Then the mixer was stopped for one minute, so that absorption could take place. After this absorption period, the mixer was restarted and the cement plus the remaining water and the polymer modifiers were added to the mix and agitated for an additional period, of approximately five minutes. The mix was emptied out when it appeared to be workable and ready. The mixer used in this study was a 3.5 cubic feet rotary drum mixer.

Type 1 Lone Star Cement was used in all of the study mixes. The fine to coarse aggregate ratio was 40/60 with 55% by weight of the coarse aggregate fraction being a medium size (passing the 3/4 in., retained on the 1/2 in. sieve) and 45% by weight of the coarse aggregate fraction being a small size (passing the 1/2 in., retained on the No. 4 sieve). All of the non-solids in the polymer modifiers were regarded as part of the water used for mixing. The dosages of polymer modifiers used in the mixes were measured according to information supplied by the manufacturers. Two gallons of additive per sack of cement were used for the mixes of Duralguard, while 3.5 gallons per sack of cement were used for all of the other polymer mixes.

During the mixing operations, the slump, air content and the unit weight were determined for each mix. Specimens were prepared with cylinders made for each age (7 and 28 days) for compressive strengths, indirect tension and splitting tensile; beams made for each age (7 and 28 days) for flexural strengths, for abrasion resistance at 28 days, and also for resistance to freezing and thawing to 300 cycles. Three (3) specimens were made for length change of hardened concrete at 28 days with initial readings at 24 hours. The setting time of concrete mixtures, using mortar screenings in gallon cans, was determined by penetration resistance. Three (3) block specimens each were made for both scaling tests and 90-day chloride permeability tests using a modified FHWA chloride penetration test (see Attachment B, Appendix).

The following tests were performed on all of the polymer modified concrete specimens:

(1) Compressive strength tests, 7 and 28 days (ASTM C-39),

(2) Flexural strength tests, 7 and 28 days (ASTM C-78),

(3) Splitting tensile strength tests, 7 and 28 days (ASTM C-496),

(4) Abrasion resistance at 28 days (ASTM C-418),

(5) Indirect tension at 7 and 28 days,

(6) Length change of hardened concrete at 28 days with initial reading at 24 hours (ASTM C-157),

(7) Time of setting of concrete mixtures by penetration resistance (ASTM C-403),

(8) Resistance to rapid freezing and thawing to 300 cycles (ASTM C-666, Procedures "B"),

(9) Shear bond strength tests, (Arizona Slant Shear Test, Modified (1)),

(10) Scaling resistance tests (ASTM C-672), and

(11) 90-day chloride permeability tests (modified FHWA procedures, see Attachment B, Appendix).

Results and pertinent information were summarized to give comparative evaluations of all the products.

DISCUSSION OF RESULTS

General Discussion

Test results have shown that these polymer modified concretes performed well, as was expected from the previous results of the FHWA testing. In a few cases, however, individual test results varied somewhat from the normal. Some of the tests were re-run, especially when results appeared to indicate there was a need to check the results.

As shown in Table 1 on page 7, the slumps of the various mixes did range from 2-3/4 in. to 7 in., the water-cement (w/c) ratios ranged from 0.22 to 0.37 for the polymer modified concretes and was 0.47 for the control mix. The air contents ranged from 2.9% to 6.6% for the polymer modified concretes and was 1.5% for the control mix. From the above data it was concluded that the polymer modified concretes tended to have a higher slump, a lower water cement ratio and a higher air content. However, workability was not improved since the slump loss was rapid. Polymer modified concrete generally had a lower unit weight than the reference concrete.

The plastic concrete made with Dow Modifier "A" had a high slump (7 in.) with satisfactory workability. The concrete mix tended to dry up rapidly. Plastic concrete using Thermoflex 8002 was dense and of a glutinous consistency, also having a tendency to dry out rapidly. Some shrinkage-like cracks appeared on the surface of some of the specimens after molding. The plastic concrete made with Arco-Dylex 1186 hardened rapidly after being discharged from the concrete mixer. In approximately 10 minutes it became difficult to finish the concrete and the slump values dropped from 6-1/2 in. to 2-3/4 in. in a little over 5 minutes.

TABLE 1

PLASTIC CONCRETE PROPERTIES

Product	Unit Wt. (lbs./ft.^{3})	w/c ratio	Slump, In.	Air Content, %
Control, ref.	146.0	0.47	3 1/4	1.5
Dow Modifier "A"	142.8	0.37	7	2.9
Thermoflex 8002	146.4	0.22	4 1/2	3.7
Arco-Dylex 1186	144.4	0.30	6 1/2	Not Run
Duralguard Modifier "E"	142.8	0.35	3 3/4	6.6

The Duralguard Modifier "E" consisted of two components, a base and a hardener, which were mixed together at a one to one ratio before being added to the concrete mix. The plastic concrete mix looked good when it was discharged from the concrete mixer, the mix being dense and tacky. Specimens were somewhat hard to finish and the concrete dried rapidly and lost it's workability.

In general, workability and time of finish for polymer modified concretes were critical. Physical and chemical characteristics of these products are listed in the Appendix.

Discussion of Strength Results

Table 2 on page 10, gives a summary of all strength results obtained on this research study. Polymer modified concretes made with Thermoflex 8002, Arco-Dyles 1186 and Duralguard Modifier "E" all gave good strength results (109% or better of the control mix strengths, 120% average). These strengths included compressive strengths, flexural strengths and splitting tensile strengths, both at 7 days and 28 days age. Concrete made with Dow Modifier "A" gave strengths somewhat lower with first run compressive strengths at 82-90% of the control mix strength, flexural strengths at 106-115% of the control mix strengths and the splitting tensile strengths at 91-94% of the control mix strengths. Another mix was run to check these relatively lower strength results. On the second run, compressive strengths at 7 and 28 days gave 103-104% of the control mix strengths.

Indirect tension test results are shown in Table 7 found in the Appendix. Basic properties determined through these tests are listed in this table. The procedures under which these results were obtained are in the developmental stage and have not yet been approved. Although every effort was made to proceed as precisely as possible, the reliability of this data should not be taken for actual values, but only for comparative purposes.

All the specimens in this study were tested for shear bond strength and exhibited good characteristics in bonding to conventional, hardened concrete. The procedures for molding these specimens are described as follows:

For the purpose of the shear bond test, 3" x 6" cardboard molds were filled with conventional concrete, cured in the moist room (100% relative humidity) for 28 days, then cut in half with a diamond saw blade at a 45° angle to the vertical. One-half of each cylinder was placed in other cardboard molds and the polymer modified concrete (for each type) was poured into the vacant upper half after mortar from the latex mix was brushed onto the bonding plane. These cylinders were placed in the moist room at 100% relative humidity after 24 hours of curing under wet burlap. The bond was tested at 7 days and 28 days under compression loading.

The test results, as seen in Table 2 on page 10 show, the failure of composite cylinders is comparable to the failure of monolithic cylinders made with the same polymer modifiers.

Shear bond strengths on the polymer modified concretes (except for Duralguard Modifier "E") ranged from 3309 to 3979 psi or about 78% to 94% of the monolithic cylinder strengths of that product. However, Duralguard Modifier "E" had shear bond strengths of 5084 to 5719 psi or about 105% to 109% of the product's monolithic cylinder strengths, but much higher than the other polymer modified concretes. Figures 2 and 3 in Appendix show typical cylinder shear bond breaks. Figure 4 in Appendix shows curves for all the breaks.

Generally all the polymer modified concretes had good strength characteristics, except Dow Modifier "A" which showed strength results just above the normal concrete. Normally Class A and Class AA 28 day compressive strength requirements are 3,800 psi and 4,200 psi, respectively.

TABLE 2

Strength Properties

Type Concrete	Age, Days	Compressive Strength psi	% of Control	Flexural Strength psi	% of Control	Splitting Ten. Strength, psi	% of Control	Bond Shear Strength psi	% Bond to Compr. Str.
Control, reference	7	3475	-	356	-	348	-	-	-
	28	4132	-	639	-	441	-	-	-
Dow Modifier "A"	7	2853	82	589	106	327	94	3368	94
	28	3737	90	737	115	403	91	3822	89
	*7	3587	103	-	-	-	-	-	-
	*28	4299	104	-	-	-	-	-	-
Thermoflex 8002	7	4134	119	797	193	467	134	3309	80
	28	5027	122	1061	166	538	122	3964	79
Arco-Dylex 1186	7	4178	120	805	145	456	131	3633	87
	28	5133	124	899	141	480	109	3979	78
Duralguard Modifier "E"	7	4670	134	766	138	477	137	5084	109
	28	5448	132	813	127	506	115	5719	105

*Compressive Strengths were re-run to check low strengths obtained.

Discussion of Durability Results

Durability test results, as summarized in Table 3 on page 13, show that all of the polymer modified concretes had fairly good results. Thermoflex 8002 and Duralguard Modifier "E" both went 300 cycles of freezing and thawing, giving durability factors of 76 and 78 respectively, in addition to good scaling resistance results both going 50 cycles with ratings of 1. A rating of 1 means very slight scaling (1/8-inch depth, maximum, no coarse aggregate visible).

Arco-Dylex 1186 and Dow Modifier "A" both went into the lower 200's of freezing and thawing cycles and had durability factors in the 40's which were not as good as the other two polymer modified concretes, but still better than the normal concrete. However, the Dow Modifier "A" had a scaling resistance rating of 4 after 50 cycles, which is better than the control mix, but not satisfactory otherwise. The control mix had a rating of 5 after 14 cycles. A rating of 4 means moderate to severe scaling and a rating of 5 means severe scaling (coarse aggregate visible over the entire surface). Figures 5, 6, 7, and 8 in the Appendix show typical scaling and freeze-thaw specimens.

The coarse aggregate used in all these concrete mixes was regular Class A gravel (Baywood), which consisted principally of chert with some particles of a white chalky substance known as weathered opal with a chemical formula of $SiO_2 \cdot nH_2O$. This particular weathered opal aggregate has a high absorption rate, which causes early failures in freeze and thaw tests, especially in non air-entrained concrete mixes. Increased resistance of polymer modified concretes over the conventional concrete indicates their effectiveness against freezing and thawing. It is believed that if a stronger coarse aggregate (i.e. limestone) was used with polymer modified concretes, even better results might be obtained in freezing and thawing durability tests. Naturally, air-entrained mixes do better, so that a combination of all of these attributes may do a very satisfactory job of protection against the freezing and thawing environment and the deicing salts.

The abrasion resistance results were good on all of the product mixes with hardly any variation in results. Abrasion resistance readings of 0.02 or 0.03 cm^3/cm^2 after 28 days were shown on the product mixes.

Discussion of 90-day Chloride Permeability Results

Table 4 on page 14 and Figure 1 on page 15 show 90-day chloride permeability results for all the polymer modified concretes at the 95% chloride level at the two depths shown. One depth, marked "a" on Figure 1, is the 1/16 - to 1/2-in. depth and the other, marked "b" on Figure 1, is the 1/2 - to 1-in. depth. Table 4 also gives standard deviations and the average chloride contents for each depth level on the various polymer modified concretes.

Samples were taken from the ponded blocks for each mix. These samples were taken in the form of pulverized concrete at depth ranges of 1/16 - to 1/2-in. and 1/2 - to 1-in. No water was used in this process. The amount of accumulated chloride ions in each sample was determined through chemical process and the 95% chloride level was determined. The 95% chloride level is a statistical value, which indicates that 95% of the chloride levels encountered in the sample will be less than or equal to that value at that particular depth. It is based on the sample mean, standard deviation and the assumption that the data is normally distributed. The 95% chloride level is generally considered a better measure of overall permeability than the average mean value.

TABLE 3

DURABILITY DATA

Type Concrete	Freeze & Thaw Cycles	Freeze & Thaw Durability Factor	Scaling Resistance Cycles	Scaling Resistance Rating*	Abrasion Resistance, 28 days, cm^3/cm^2
Control, ref.	70	14	14	5	0.02
Dow Modifier "A"	243	47	50	4	0.03
Thermoflex 8002	300	76	52	1	0.02
Arco-Dylex 1186	201	40	50	1	0.02
Duralguard Modifier "E"	300	78	50	1	0.03

*Rating for Scaling to Deicer Agents

0 - no scaling
1 - very slight scaling
2 - slight to moderate scaling
3 - moderate scaling (some coarse aggregate visible)
4 - moderate to severe scaling
5 - severe scaling (coarse aggregate visible near entire surface)

TABLE 4

90-DAY CHLORIDE PERMEABILITY DATA

Type Concrete	Sample Depth, inches	Chloride Absorbed ($lbs. cl^-/yd.^3$) Standard Deviation	Average	95% cl^- level*
Concrete, ref.	1/16 - 1/2	1.42	14.03	16.40
	1/2 - 1	2.64	3.36	7.70
Dow Modifier "A"	1/16 - 1/2	1.48	6.40	8.83
	1/2 - 1	0.75	0.45	1.68
Thermoflex 8002	1/16 - 1/2	0.87	1.01	2.44
	1/2 - 1	0.46	0.32	1.08
Arco-Dylex 1186	1/16 - 1/2	2.08	3.10	6.52
	1/2 - 1	0.81	0.89	2.22
Duralguard Modifier "E" 1st run	1/16 - 1/2	6.92	8.60	20.80
	1/2 - 1	0.60	1.40	2.40
2nd run	1/16 - 1/2	3.14	12.20	17.36
	1/2 - 1	1.74	3.90	6.80

*NOTE: Acceptance Criteria are as follows: The 95% absorbed chloride levels for latex modified concrete shall be less than 0.32% for 1/16 to 1/2 inch level and less than 0.064% for 1/2 to 1 inch level. (To convert cl/yd^3 to percent chloride by weight of concrete, multiply by 0.0255) Chloride Absorbed: total chloride minus average baseline (before ponding) chloride. The 95% chloride content is statistically obtained value which indicates that 95% of the chloride contents in the sample will be less than or equal to that value. A normal distribution is assumed and it is calculated as follows: 95% cl level = average cl + standard deviation (x) where x is constant = 1.645

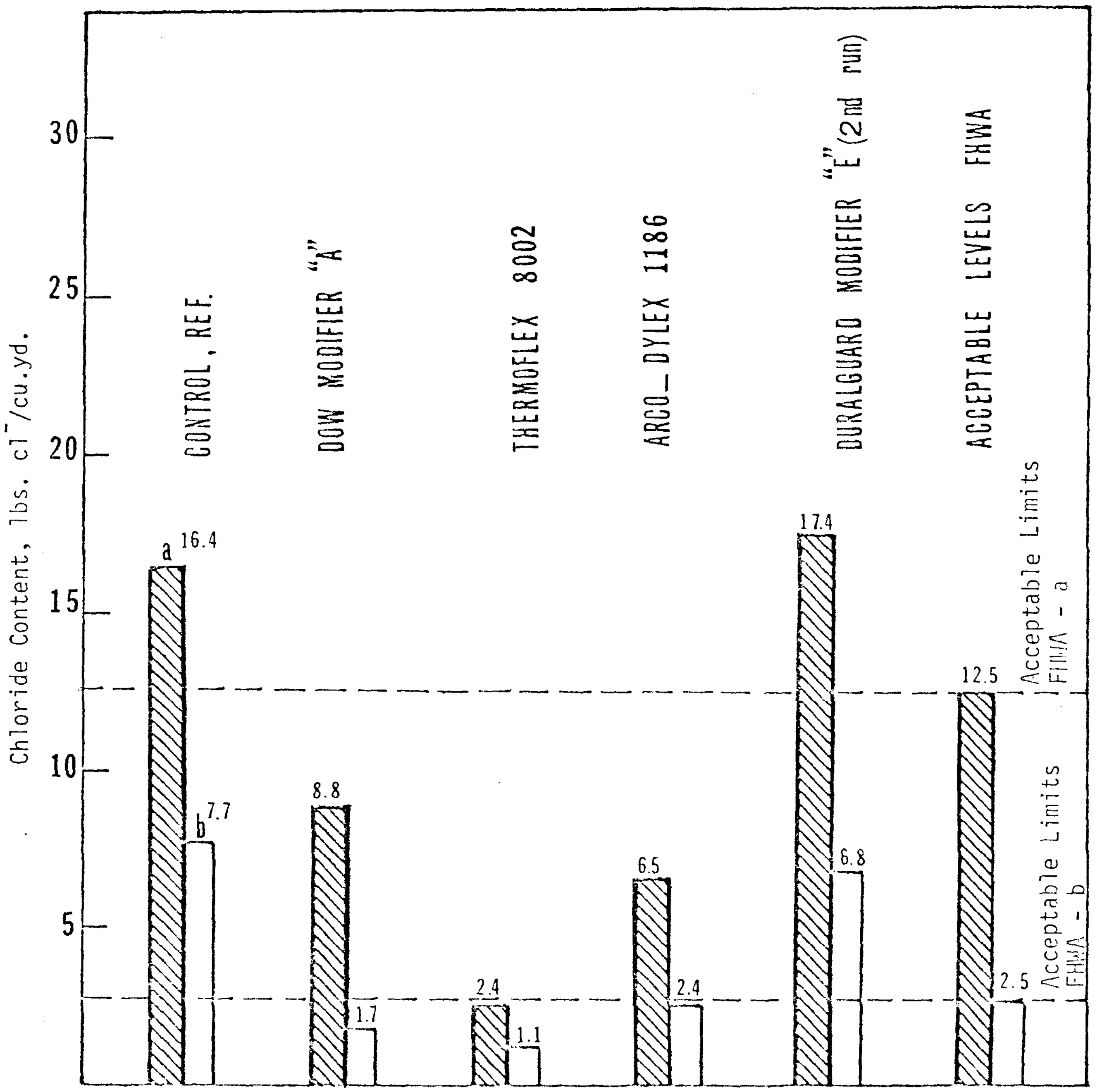

FIGURE 1

95% Chloride Levels

a - Depth 1/16 - 1/2 inch
b - Depth 1/2 - 1 inch

All the polymer modified concretes, except Duralguard Modifier "E", showed satisfactory results at both depths for the 95% chloride level. As a check, a second series of tests were run on Duralguard Modifier "E". The first test series showed that the 1/16 - to 1/2-in. depth had an excessive chloride level of 20.00 $lbs./yd.^3$, while the 1/2 - to 1-in. depth was slightly under the acceptable level of 2.50 $lbs./yd.^3$. The second test series showed that both depths had excessive chloride levels. The FHWA suggested acceptable 95% chloride levels were 12.55 $lbs./yd.^3$ of concrete or a 0.32% of Cl by weight of concrete at the 1/16 - to 1/2-in. depth and a 2.50 $lbs./yd.^3$ of concrete or 0.064% of Cl by weight of concrete at the 1/2 - to 1-in. depth. Figure 1 on page 15 shows all the 95% chloride level results for all the polymer modified concretes.

Discussion of Other Results

The time of setting was determined by ASTM C-403 for all the polymer modified concretes and results are listed in Table 5 on page 17. Generally, the time of setting was within one hour of the control or reference concrete mix. An exception was Dow Modifier "A", which had an initial set of 1 hour 15 minutes longer and a final set of 2 hours 9 minutes longer. All the products had a retarding action as compared to the control or reference mix, except Duralguard Modifier "E", which had an accelerating action as compared to the control, or reference, mix.

The dry shrinkage test, or the length change of concrete, was determined by ASTM C-157 and results are reported in Table 6 on page 17. Thermoflex 8002 concrete averaged out as having no change in length on three (3) specimens with one (1) specimen having no change, another specimen having a slight increase in length and the other specimen having a slight decrease in length. Arco-Dylex 1186 concrete showed a 1.12% decrease in length average for three (3) specimens, while Duralguard Modifier "E" concrete showed a 1.89% decrease in length average for the three (3) specimens. However, Dow Modifier "A" concrete showed an average 0.81% increase in length change for three (3) specimens.

TABLE 5

TIME OF SETTING DATA

Type Concrete	Time of Setting, hours - minutes Initial	Final
Control, Ref.	4-15	6-9
Dow Modifier "A"	5-30	8-18
Thermoflex 8002	4-54	6-55
Control, Ref.	6-9	8-39
Arco-Dylex 1186	6-54	9-33
Control, Ref.	6-21	8-36
Duralguard Modifier "E"	5-45	7-42

TABLE 6

LENGTH CHANGE OF CONCRETE PROPERTIES

Type Concrete	Dow Modifier "A"	Thermoflex 8002	Arco-Dylex 1186	Duralguard Modifier "E"
		Unit of Measure, inches		
Initial Reading, (Ave. of 3)	~~.0016~~ 0.1985	.1849	.1960	.1795
After 32 weeks, Final Reading, (Ave. of 3)	.2001	.1849	.1938	.1761
Difference, (Ave. of 3)	+.0016	0	-.0022	-.0034
%Difference, (Ave. of 3)	+0.81	0	-1.12	-1.89

CONCLUSIONS

The following observations or conclusions have been reached from the testing results obtained in this laboratory research study:

1. Generally, all of the polymer modified concretes already approved by the Federal Highway Administration and tested under Louisiana conditions showed satisfactory results, although some products showed better results than others in some areas.
2. Polymer modified concrete had showed a very good resistance to freezing and thawing and the resistance to scaling was good on all the products, except Dow Modifier "A".
3. Resistance against the penetration of chloride ions was satisfactory for all the products, except Duralguard Modifier "E" which has an excess of allowable limit on chloride ions at the depths tested.
4. Strength characteristics of the polymer concretes improved approximately 20%, on the average, above the conventional concrete, although Dow Modifier "A" concrete was slightly above the normal concrete in strength characteristics.
5. Good shear bond strength was developed by the polymer modified concretes to the conventional hardened concrete.
6. Fresh plastic concrete made with these polymer modifiers had a tendency to lose its workability and slump rapidly.

RECOMMENDATIONS

The following recommendations are being made in this final report:

1. The polymer modified concretes included in this study, already on the FHWA approved list, should be accepted for use in the State of Louisiana as bridge deck overlay alternate bid items to the Iowa Dense Concrete.
2. Since the reduction of penetration of the chloride ion into the concrete is of major importance and the new product, Duralguard Modifier "E", failed to meet the suggested acceptable 95% chloride levels at the particular depths, this product should not be placed on the Qualified Products List for bridge deck chloride protection.
3. Generally, since the polymer modified concretes lose their workability and slump rapidly, extra effort should be made in control of their use on bridge deck overlay construction.

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APPENDIX

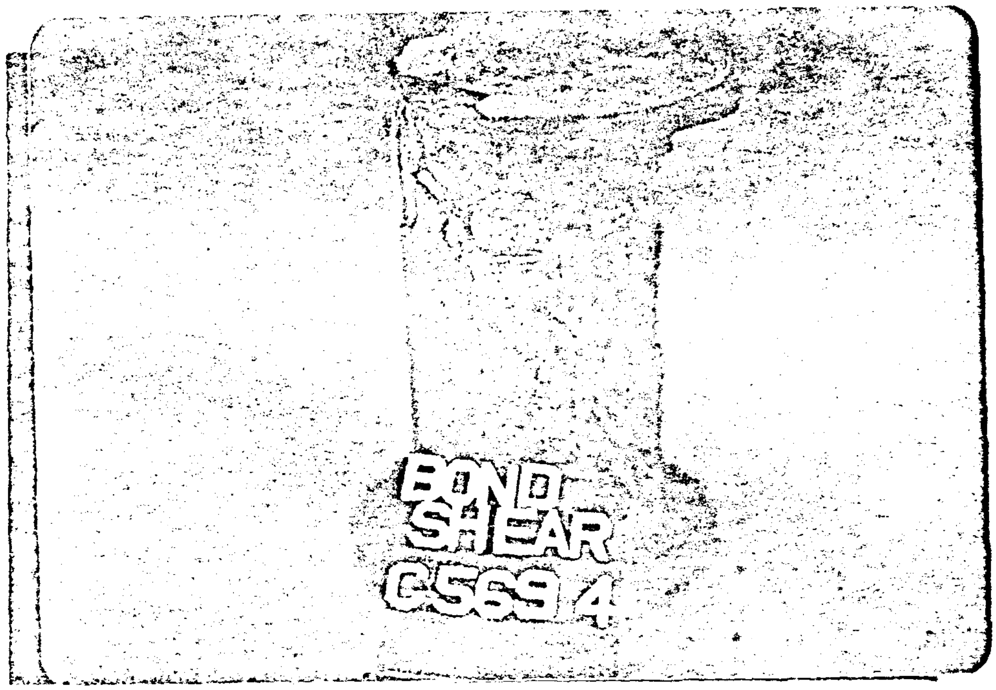

FIGURE 2

Shear Bond Test Specimen, 28 days, Duralguard

FIGURE 3

Shear Bond Test Specimen, 7 days, Thermoflex

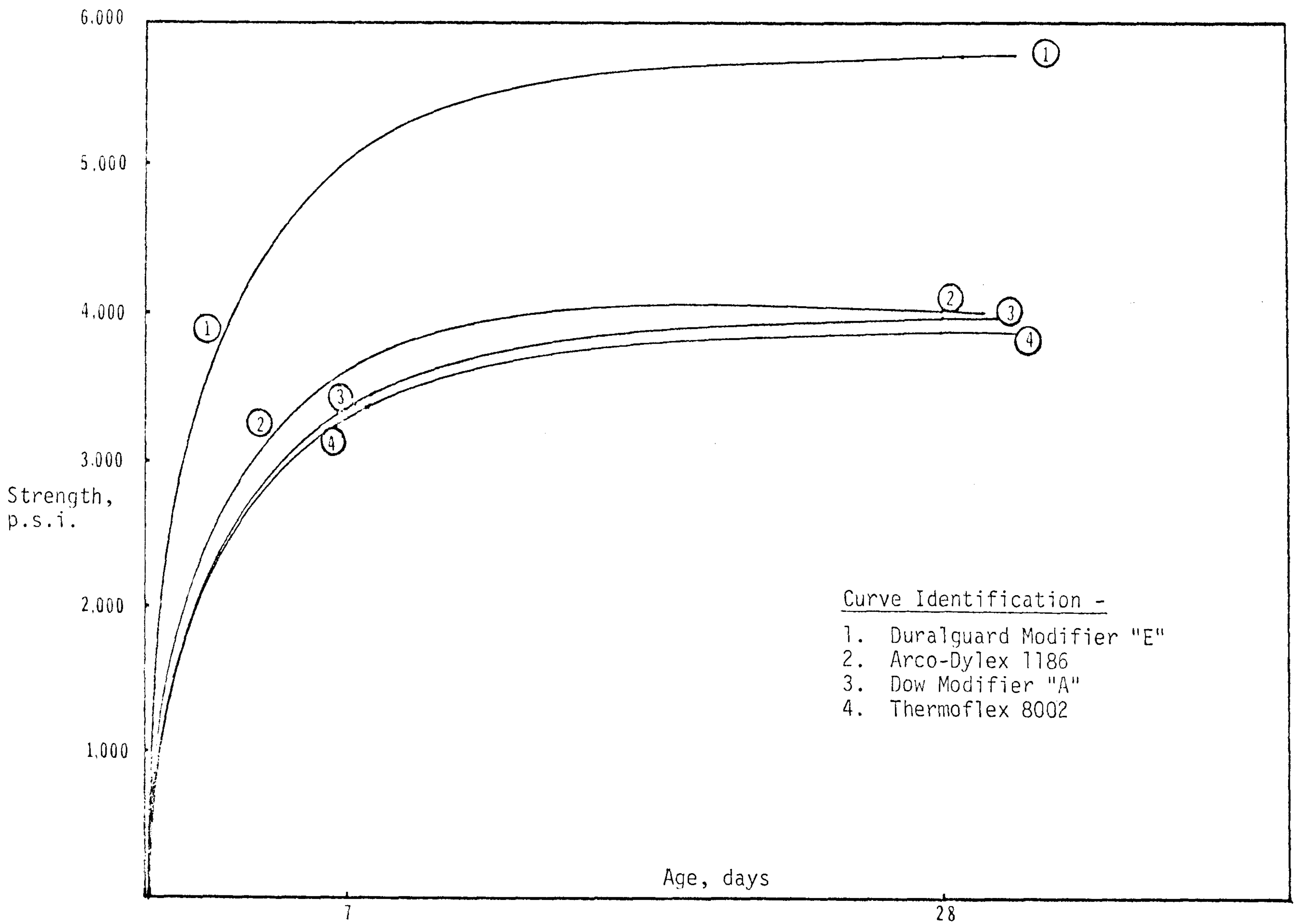

FIGURE 4

Shear Bond Strengths VS Time Curves

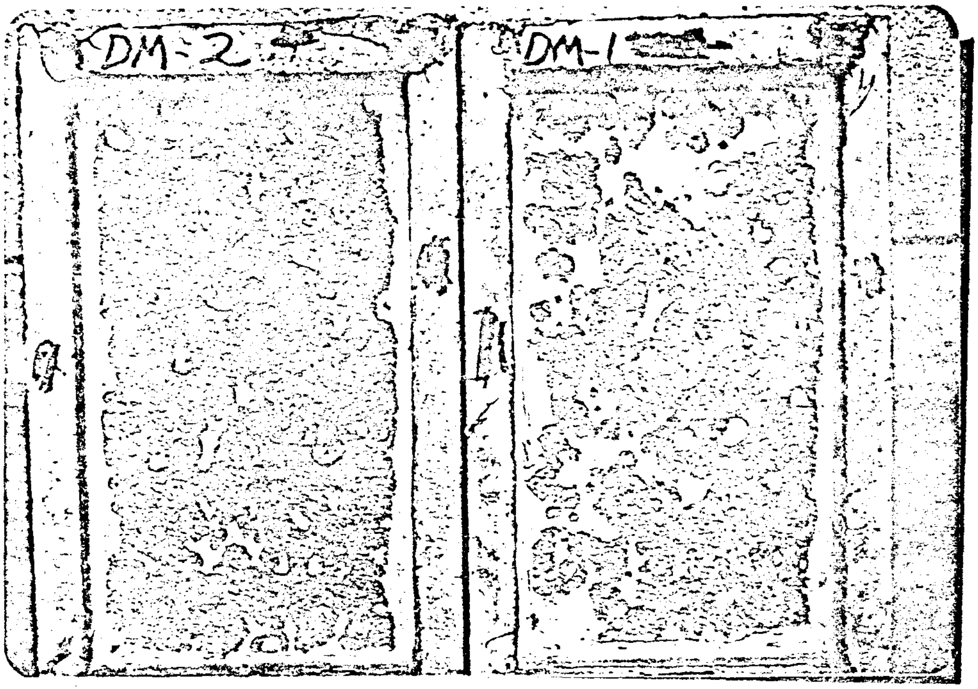

FIGURE 5

Scaling Blocks, Dow Modifier "A"

FIGURE 6

Freeze and Thaw Specimens

Dow Modifier "A"

FIGURE 7

Scaling Blocks, Thermoflex

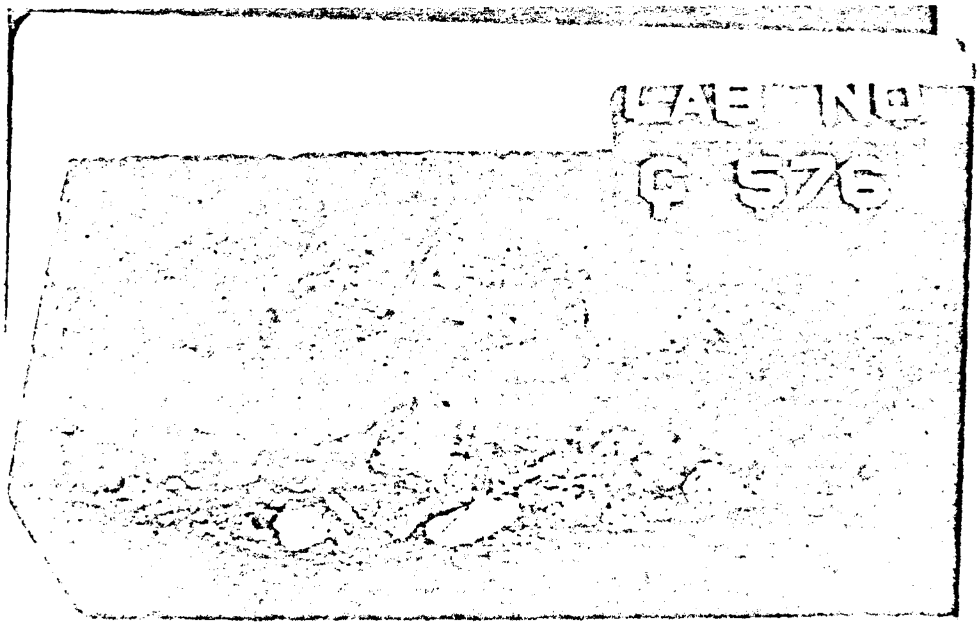

FIGURE 8

Freeze and Thaw Specimens

Thermoflex

TABLE 7

Indirect Tension Test
Property Results

Type Concrete	Age, Days	Modulus of Elasticity, 1×10^6 p.s.i.	Poisson's Ratio, in./in.	Stress Failure, p.s.i.
Control, reference	7	1.80	0.293	400
	28	1.50	0.2741	442
Dow Modifier "A"	7	3.46	0.060	431
	28	3.20	0.198	554
Thermoflex 8002	7	1.60	0.288	605
	28	2.53	0.273	731
Arco-Dylex 1186	7	1.71	0.255	583
	28	2.84	0.1215	665
Duralguard	7	2.50	0.233	595
Modifier "E"	28	Not Run	Not Run	Not Run

*NOTE: All values are average of three (3) specimens (approximately 1/3 of a 6 x 12 inch cylinder).

The procedures under which these results were obtained are in the developmental stage and have not yet been approved. Although every effort was made to proceed as precisely as possible, the reliability of this data should not be taken for actual values, but only for comparative purposes.

PHYSICAL PROPERTIES

Product Commercial Name	Manufacturer
Dow Modifier "A"	Dow Chemical Company, U.S.A. 3636 Richmond Avenue Houston, Texas 77027

Physical Properties, Supplied by the Manufacturer

Polymer Type......................Styrene-Butadiene

Percent Solids....................46.0-49.0

Weight per gallon.................8.4
(lbs. at 25°C.)

Color.............................White

Stabilizers.......................

(a) Latex......................Non ionic surface

(b) Portland Cement
Composition..............Polydimethyl siloxane

Other Information.................N.A.

Product Commercial Name	Manufacturer
Thermoflex 8002	Thermoflex, Inc. 2927 Griffith Avenue P. O. Box 21134 Louisville, Kentucky

Physical Properties, Supplied by the Manufacturer

Polymer Type......................Styrene 1, 3 Butadiene-Co-Polymer Latex Emulsion

Percent Solids....................46.0-48.0

Weight per gallon.................8.1-8.5
(lbs. at 25°C.)

Color.............................White

Stabilizers.......................

(a) Latex.....................N.A.

(b) Portland Cement Composition..............N.A.

Other Information.................2 years (min.) shelf life
ph - 10.5-11.5

PHYSICAL PROPERTIES (Continued)

Product Commercial Name	Manufacturer
Arco-Dylex 1186	A. C. Coffman Company, Inc. P. O. Box 5458 Clearwater, Florida Arco-Polymers, Inc. Subsidiary of Atlantic Richfield Company Research & Development P. O. Box 208 Monara, Pa 15021

Physical Properties, Supplied by the Manufacturer

Polymer Type.......................Styrene-Butadiene

Percent Solids....................48.4

Weight per gallon.................N.A.
(lbs. at 25°C.)

Color.............................N.A.

Stabilizers.......................

(a) Latex.......................N.A.

(b) Portland Cement
Composition.............N.A.

Other Information.................ph at 25°C = 9.6
Surface Tension = 40
Viscosity, cps at 25°C = 35

PHYSICAL PROPERTIES (Continued)

Product Commercial Name	Manufacturer
Duralguard Modifier "E"	Dural International Corporation 95 Brook Avenue Dear Park, New York 11729

Physical Properties, Supplied by the Manufacturer

Polymer Type......................Two part, base and hardener, 1/1
Emolsified Epoxy Polymer

Percent Solids....................48.6 hardener
74.9 base

Weight per gallon.................N.A.
(lbs. at 25°C.)

Color.............................White, milky

Stabilizers.......................

(a) Latex.....................N.A.

(b) Portland Cement
Composition.............N.A.

Other Information.................Components are thin, amber colored
liquid, when mixed turn milky white

Total Solids-Latex, Percent

Scope

This envolves the determination of the percent solids on all latex samples. It involves weighing a sample of wet latex, drying it in an oven and then expressing the weight ratio of dry/wet in percent

Procedure

(a) All samples to be tested must be at room temperature. If the sample is warm it can be cooled in a pan of cold tap water.

(b) The level of the balance should be checked and adjusted if necessary. Also the zero of the balance should be checked and adjusted correspondingly.

(c) Weigh three aluminum cups and record the weight of each (tare weight). Note: Every sample tested must be done in triplicate.

(d) Mix by hand each sample when cool by inverting the container five to ten times.

(e) Weigh approximately one gram of latex to the nearest milligram into each preweighed aluminum cup.

(f) Place all three samples in the oven to dry for 120 minutes (over temperature 285 ± 1°F.)

(g) Remove the samples from the oven and place immediately in a desicator for a few minutes or until cool. This prevents moisture pick up from the air while cooling.

(h) Reweigh each sample out of the desicator to the nearest milligram and record.

(i) Calculations.

$$\text{Total solids in percent} = \frac{C-A}{B-A} \times 100$$

A - The weight of the empty aluminum cup.
B - The weight of the aluminum cup and the wet sample.
C - The weight of the aluminum cup and dried sample.

(j) Continuation of Calculations.

Example:

If: A = 1.374 g.
B = 2.355 g.
C = 1.779 g.

Then (C-A) = 1.779 − 1.374 = 0.405 g.

(B-A) = 2.355 − 1.374 = 0.982 g.

Therefore: $\frac{(C-A)}{(B-A)} \times 100 = \frac{0.405}{0.982} \times 100 = 41.2$ percent solids

(k) Results

(1) If all three samples are within 2 percent, average the three samples to obtain the percent solids.

(2) If all three samples are not within 2 percent, but two samples are within 1 percent, the average between the two samples within 1 percent is reported as the percent solids and the third determination is discarded.

(3) If all three samples are not within 2 percent and no two are within 1 percent, all the values must be discarded and the solids procedure must be repeated.

90-Day Chloride Permeability Test for

Styrene Butadiene Latex Modified Concrete

(a) Four 9" X 15" X 3" plain concrete slabs shall be overlaid with 1-1/4 inches of latex modified concrete proportioned as follows: w/c = 0.30 to 0.40, CF = 6.5, percent fine aggregate in total aggregate = 60, slump = 4 to 6 inches, maximum size coarse aggregate = 1/2 inch, latex content = 23.8 gal./$yd.^3$ of concrete.

(b) The slabs shall be cured with wet burlap for 24 hours after molding. After curing the molds shall be removed and the slabs shall be placed in a 73.4° ± 3°F., 50 ± 4 percent rh environment for 19 days.

(c) Following this conditioning (i.e. on the 21st day), 1/8 ± 1/16 inches of the slab surface shall be abraded away using grinding or sandblasting techniques. No water shall be used in the abrading process.

(d) Place the slabs in the 73.4° ± 3°F., 50 ± 4% rh environment for an additional 7 days.

(e) 1-inch high X 1-inch wide dams shall be placed around 3 of the specimens. All 4 slabs shall then be placed in a 73.4° ± 3°F 50 ± 4% rh environment for 90 days. Three of the slabs shall be subjected to continuous ponding with 1/2-inch deep 3 percent sodium chloride solution during the 90 days. Glass plates shall be placed over the 3 ponded specimens to retard evaporation of the solution, and additional solution shall be added when necessary to maintain the 1/2-inch depth.

(f) After 90 days of ponding, the solution shall be removed from the slabs, and after drying, the surfaces shall be wire brushed until all salt crystal buildup is completely removed.

(g) Samples for chloride analysis shall then be taken from all 4 slabs, in accordance with the rotary hammer procedure described in report FHWA-RD-74-5 or by dry coring (1.5-inch minimum diameter cores) and dry sawing. Three samples shall be obtained form each slab at the following depths.

1/16 inch to 1/2 inch
1/2 inch to 1 inch

(h) The baseline chloride content for the overlay concrete shall be determined as the average chloride content of samples obtained from the 1/16 inch to 1/2 inch and 1/2 inch to 1 inch depths within the slab that was not ponded with 3 percent NaCl solution.

(i) The absorbed chloride content of each sample from the 3 ponded slabs shall be determined as the difference between the total chloride content of that sample and the baseline value calculated in item (h) above. If the result is less than zero, the result shall be reported as 0.0. The average chloride absorbed at each sampling depth shall be calculated.

(j) Reporting shall include:

(1) Each total chloride value determined in item (g).
(2) The average and maximum baseline chloride in item (h).
(3) Each calculated absorbed chloride value determined in item (i).
(4) The average and maximum absorbed chloride values calculated in item (i) for each depth.

E R R A T A

To the report - Polymer Modified Concrete Study, Research Report No. FHWA/LA-80/139, State Project No. 736-04-52, Research Project No. 78-2C(B), please make the following corrections:

1. Name of the product, "Arco-Dylex 1186", mentioned throughout the report, should be changed to "Dylex Latex 1186 Modifier", as listed per the following locations:

   Form DOT F 1700.7 - Abstract, 3rd line
   page ix - 2nd line, conclusion 1. on 1st line
   page xi - 3rd line
   page 1 - 3rd paragraph, 5th line
   page 3 - 2nd paragraph, 4th line
   page 6 - 3rd paragraph, 7th line
   page 7 - Table 1
   page 8 - 1st paragraph, 3rd line
   page 10 - Table 2
   page 11 - 2nd paragraph, 1st line
   page 13 - Table 3
   page 14 - Table 4
   page 15 - Figure 1
   page 16 - 3rd paragraph, 6th line
   page 17 - Table 5 and Table 6
   page 26 - Figure 4
   page 29 - Table 7

2. In the Physical Properties, as shown on page 32, the top portion should be changed to:

Product Commercial Name	Manufacturer
Dylex Latex 1186 Modifier	Tex-Crete, Inc. 42289 Delany Road Zion, Illinois 60099 Polysar Latex Division of Polysar Incorporated Chattanooga, Tennessee 37406 Research and Development P. O. Box 208 Monaca, Pa. 15021

3. In addition, in Table 6 on page 17, the corrected contents of the table should be:

TABLE 6

LENGTH CHANGE OF CONCRETE PROPERTIES

Type of Concrete	Dow Modifier "A"	Thermoflex 8002	Dylex Latex 1186 Modifier	Duralguard Modifier "E"
		Unit of Measure, inches		
Initial Reading, Ave. 0 3	.1985	.1849	.1960	.1795
After 32 weeks, Final Reading, Ave. of 3	.2001	.1849	.1938	.1761
Difference, Ave. of 3	+.0016	0	-.0022	-.0034
% Difference, Ave. of 3	+0.81	0	-1.12	-1.89