Drying Shrinkage in P.C. Concrete

Final Report for MLR-89-5

March 1990

Highway Division
Iowa Department of Transportation

Final Report
for
Materials Laboratory Research
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DISCLAIMER

ABSTRACT

Crack formation has been a problem on some recently constructed bridges in Iowa. Drying shrinkage has been considered a contributing factor in that cracking.

The study was undertaken to evaluate some of those material properties that contribute to the magnitude of drying shrinkage. Cement content, cement composition, fly ash and retarding admixture were the factors studied. Concrete prisms were cast for seven mixes and, after curing, were exposed to 100°F heat at ambient humidity for 280 days.

The following were observed from the testing:

1. Higher C_3A content cement concrete produced larger shrinkage.
2. Use of fly ash increased shrinkage.
3. Use of retarder increased shrinkage.
4. Lowering the cement content reduced the shrinkage.

INTRODUCTION

Drying shrinkage in portland cement concrete has long been accepted and allowed for when using concrete as a building material. Jointing is used to control where the shrinkage cracks will occur. Reinforcement in structures restrains the shrinkage. Some of the factors relating to the magnitude of the shrinkage are:

1. Water to cement ratio
2. Curing temperatures
3. Cement composition
4. Moisture content
5. Admixtures
6. Aggregate content
7. Aggregate stiffness
8. Aggregate specific surface

In Iowa, shrinkage of concrete has been considered a contributing factor in crack formation on some new bridge decks.(1) The Iowa bridge deck mix is considered by some to have a higher than normal cement factor. Marks concluded in an Iowa study in 1987 that, "...Based upon this research, the type of coarse aggregate, cement content or use of a retarder has little influence on the total drying shrinkage that occurs in portland cement concrete."(2) MLR-89-5 was initiated to further investigate shrinkage with Iowa materials. The conclusions on the earlier study are not consistent with generally accepted properties of concrete.

OBJECTIVE

The objective of the study was to identify factors that most affect drying shrinkage in concrete.

MATERIALS

The following materials were used in the study:

Cement: Cement A, Type I, medium to low C_3A
Cement B, Type I/Type II, low C_3A
Cement C, Type I, high C_3A

Fly Ash: Ottumwa Class C

Air Entraining: Ad Aire, single strength, Carter-Waters Corp.

Retarder: Daratard 17, W. R. Grace Co.

Coarse Aggregate: Cordova, Builders Sand and Gravel (AIL516)

Fine Aggregate: Cordova, Moline Consumers Co. (AIL520)

PROCEDURES

Normal mix procedures (ASTM C192) were followed for all mixes. The mix proportions were as follows:

	1	2	3	4	5	6	7
	D Mix	D Mix	D Mix	D Mix	D Mix (Mod)	C Mix	C Mix (Mod)
Cement (#)	709 "A"	709 "B"	709 "C"	709 "A"	567 "A"	603 "A"	482 "A"
Fly Ash (#)	---	---	---	---	142	---	121
C. Agg. (#)	1442	1442	1442	1451	1460	1659	1703
F. Agg (#)	1447	1447	1447	1457	1466	1363	1399
Water (#)	256	256	273	243	243	232	227
Air (%)	6.3%	6.2%	6.1%	7.0%	6.2%	6.5%	6.1%
Retarder	---	---	---	5oz/100#	---		
w/c	0.361	0.361	0.385	0.343	0.343	0.385	0.376
28 Day Comp Str (PSI)	6000	5800	5800	5610	5550	5360	5220

Two, 4"x4"x18" beams were cast for each mix. The cure was 24 hours in steel forms covered with wet burlap followed by stripping and 6 days of moist curing. All curing was at 73°F ± 3°. The beams were placed in a forced-air oven at 100°F ± 3° after the 7-day cure. Weight and length measurements were taken at regular intervals through 280 days. The results are in Table I and II and Figure 1, 2 and 3.

DISCUSSION OF RESULTS

The differences in shrinkage among the mixes showed up early on in the testing (within 42 days after casting). Four variables were isolated in Figure 1, 2, and 3; cement brand; fly ash; retarder; and cement content.

Cement Brand Effect

Cement composition is known to influence the shrinkage. Figure 1 shows the effect of the cement brand on the shrinkage results. A correlation between C_3A content and shrinkage has been reported. In this study, higher shrinkage was observed with the higher C_3A cement. At 28 days after casting, Cement C had a 40 percent larger shrinkage than Cement B and a 17 percent larger shrinkage than Cement A.

Fly Ash Effect

Fly ash alters the composition of the paste which again influences the shrinkage. The pozzolanic properties contribute to the formation of additional calcium silicate hydrate (C-S-H) in the paste. The amount of C-S-H is a factor that contributes to creep and shrinkage in concrete. Surprisingly, Figure 2 did not show a consistent increase in shrinkage for those mixes with 20 percent fly ash over those without fly ash.

The shrinkage of the C mix with fly ash was 17 percent larger than the C mix without fly ash at 28 days. At this same age, the D mix with fly ash had a shrinkage only 6 percent higher than the comparative mix. The shrinkages throughout the test for the fly ash mixes were normally equal to or larger than the shrinkages for the comparable mixes without fly ash.

Cement Content and Admixture Effect

The use of a lower cement factor mix produced a slightly lower shrinkage at about all test ages (Figure 3). It should be noted that the aggregate fine to coarse ratio is slightly different between the comparative mixes.

The retarding admixture was a hydroxylated organic material meeting ASTM C494 Type D. Chemical admixtures are often associated with higher shrinkages. The particular retarder used increased the shrinkage 13 percent over the comparative mix with no retarder at 28 days.

SUMMARY AND CONCLUSIONS

As has been shown in much previous research, cement content; admixtures; and cement composition do have a definite effect on shrinkage of concrete. Each factor was looked at separately. It is unlikely that the factors combined would produce an additive effect on shrinkage, but certainly a larger shrinkage would be anticipated.

The following conclusions can be made based on the study:

1. Cement content, cement composition and admixtures can affect the amount of shrinkage in PC concrete.
2. The differences in the amount of shrinkage appeared within the first 42 days after casting.
3. The higher C_3A content cement concrete experienced a larger shrinkage than the comparative mixes.
4. The use of fly ash in mixes produced equal or greater shrinkage than was experienced with mixes without fly ash.
5. The mix with a retarding admixture had a higher shrinkage than the comparative mix with no retarder.
6. The lower cement factor mix had a lower shrinkage than the comparative higher cement factor mix.

REFERENCES

1. Marks, V. J., High Molecular Weight Methacrylate Sealing of a Bridge Deck, HR-2031, Iowa Department of Transportation, 1988

2. Marks, V. J., Length Change of P.C. Concrete Due to Moisture Content, MLR-85-9, Iowa Department of Transportation, 1987

TABLE 1. SUMMARY OF LENGTH CHANGE AND MOISTURE LOSS
(Average of two beams)

AGE DAYS	MIX 1 WEIGHT GRAMS	MIX 1 LENGTH CHANGES INCHES	MIX 2 WEIGHT GRAMS	MIX 2 LENGTH CHANGES INCHES	MIX 3 WEIGHT GRAMS	MIX 3 LENGTH CHANGES INCHES	MIX 4 WEIGHT GRAMS	MIX 4 LENGTH CHANGES INCHES	MIX 5 WEIGHT GRAMS	MIX 5 LENGTH CHANGES INCHES	MIX 6 WEIGHT GRAMS	MIX 6 LENGTH CHANGES INCHES	MIX 7 WEIGHT GRAMS	MIX 7 LENGTH CHANGES INCHES
1	11050	0.0245	11075	0.0267	11085	0.0235	11005	0.0201	11155	0.0217	11120	0.0185	11220	0.0274
9	10969	0.0232	10976	0.0256	10992	0.0216	10916	0.0187	11088	0.0204	11003	0.0178	11134	0.0257
14	10916	0.0213	10913	0.0243	10937	0.0193	10868	0.0162	11045	0.0185	10950	0.0159	11091	0.0239
28	10852	0.0191	10841	0.0223	10872	0.0172	10810	0.0140	10980	0.0159	10881	0.0132	11026	0.0212
42	10822	0.0177	10808	0.0209	10840	0.0158	10779	0.0126	10948	0.0150	10847	0.0123	10996	0.0206
56	10800	0.0177	10785	0.0206	10821	0.0157	10760	0.0121	10930	0.0143	10827	0.0119	10980	0.0197
84	10774	0.0168	10757	0.0192	10797	0.0152	10737	0.0118	10905	0.0142	10802	0.0112	10957	0.0196
112	10755	0.0165	10738	0.0193	10780	0.0151	10721	0.0117	10888	0.0132	10786	0.0106	10943	0.0196
140	10739	0.0166	10724	0.0194	10765	0.0149	10710	0.0116	10866	0.0126	10765	0.0099	10922	0.0182
168	10720	0.0159	10707	0.0186	10746	0.0140	10685	0.0108	10846	0.0123	10748	0.0099	10908	0.0183
196	10705	0.0157	10695	0.0179	10735	0.0137	10674	0.0103	10829	0.0122	10736	0.0097	10890	0.0182
280	10680	0.0149	10676	0.0173	10713	0.0137	10651	0.0103	10801	0.0120	10717	0.0096	10867	0.0181

TABLE 2. SUMMARY OF SHRINKAGE AND MOISTURE
(Average of two beams)

AGE DAYS	MIX 1 PERCENT MOISTURE	MIX 1 LENGTH PERCENT SHRINK	MIX 2 PERCENT MOISTURE	MIX 2 LENGTH PERCENT SHRINK	MIX 3 PERCENT MOISTURE	MIX 3 LENGTH PERCENT SHRINK	MIX 4 PERCENT MOISTURE	MIX 4 LENGTH PERCENT SHRINK	MIX 5 PERCENT MOISTURE	MIX 5 LENGTH PERCENT SHRINK	MIX 6 PERCENT MOISTURE	MIX 6 LENGTH PERCENT SHRINK	MIX 7 PERCENT MOISTURE	MIX 7 LENGTH PERCENT SHRINK
1	3.47	0.0000	3.74	0.0000	3.47	0.0000	3.33	0.0000	3.27	0.0000	3.77	0.0000	3.25	0.0000
9	2.71	0.0069	2.81	0.0061	2.60	0.0106	2.49	0.0078	2.66	0.0069	2.67	0.0039	2.46	0.0094
14	2.21	0.0178	2.22	0.0136	2.09	0.0236	2.04	0.0217	2.26	0.0175	2.17	0.0142	2.06	0.0194
28	1.61	0.0300	1.55	0.0247	1.48	0.0350	1.50	0.0339	1.66	0.0319	1.54	0.0294	1.46	0.0344
42	1.33	0.0375	1.24	0.0322	1.18	0.0428	1.20	0.0417	1.36	0.0372	1.22	0.0344	1.19	0.0375
56	1.13	0.0375	1.02	0.0342	1.00	0.0436	1.02	0.0444	1.19	0.0408	1.03	0.0367	1.04	0.0425
84	0.88	0.0428	0.76	0.0417	0.78	0.0464	0.81	0.0464	0.96	0.0417	0.80	0.0403	0.82	0.0431
112	0.70	0.0444	0.59	0.0411	0.63	0.0469	0.66	0.0464	0.81	0.0469	0.64	0.0436	0.70	0.0433
140	0.56	0.0436	0.45	0.0408	0.49	0.0481	0.55	0.0475	0.60	0.0506	0.45	0.0475	0.51	0.0511
168	0.38	0.0475	0.30	0.0453	0.30	0.0528	0.32	0.0519	0.41	0.0522	0.29	0.0478	0.37	0.0506
196	0.24	0.0489	0.18	0.0489	0.21	0.0547	0.22	0.0547	0.26	0.0528	0.18	0.0486	0.21	0.0508
280	0.00	0.0531	0.00	0.0522	0.00	0.0547	0.00	0.0547	0.00	0.0539	0.00	0.0494	0.00	0.0514

FIGURE 1. EFFECT OF CEMEMT BRAND ON SHRINKAGE

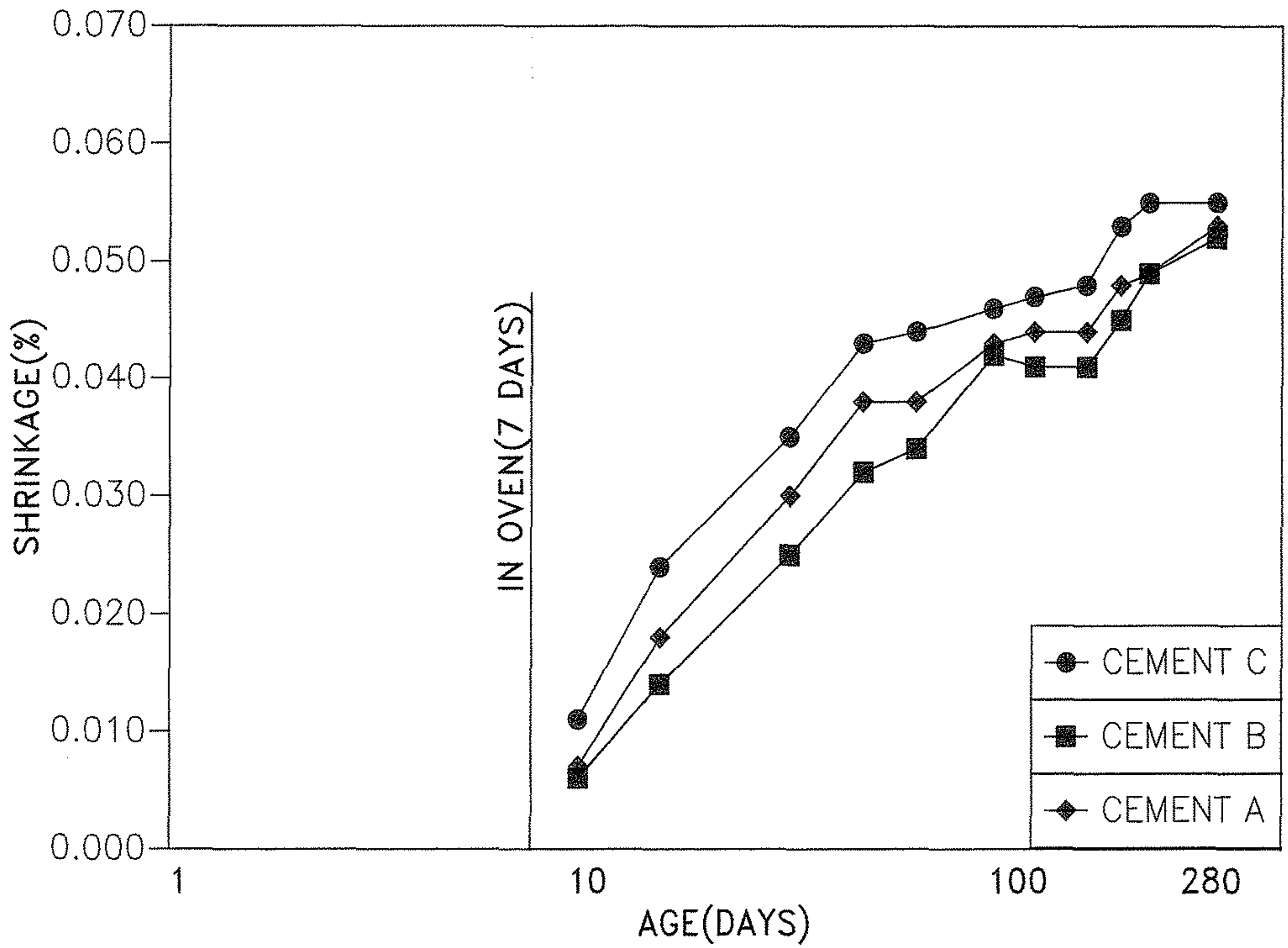

FIGURE 2. EFFECT OF FLY ASH ON SHRINKAGE

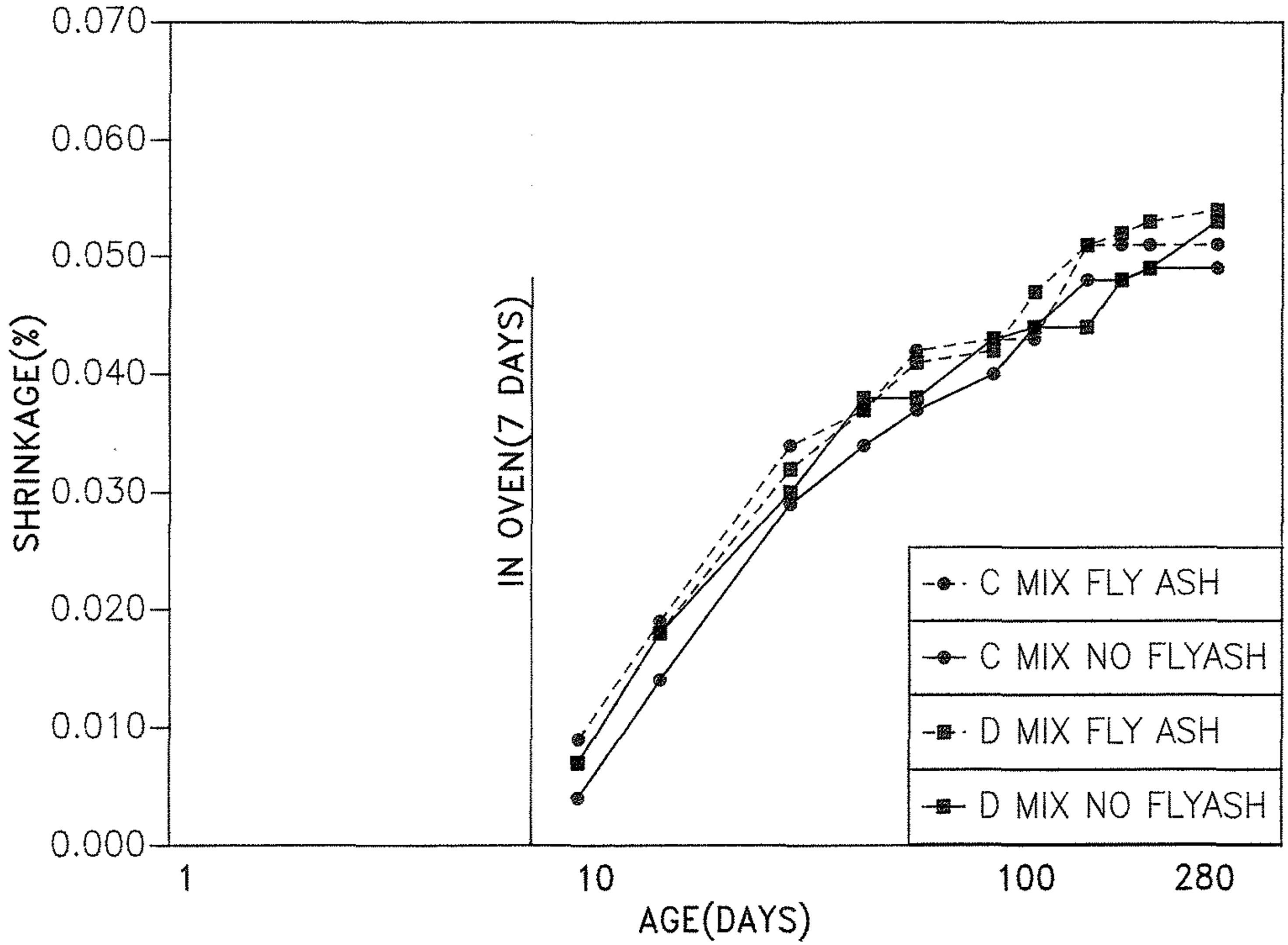

FIGURE 3. EFFECT OF CEMENT CONTENT AND RETARDER ON SHRINKAGE