**Iowa State Highway Commission**

Materials Department

Special Investigations

**Research Project R-214**

**Final Report**

# Durability of P.C. Concrete as Affected by Aggregate Size, Curing & Proportions

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# Durability of P. C. Concrete as Affected by Aggregate Size, Curing and Proportions

October 7, 1968

Ames Laboratory

by

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## ACKNOWLEDGMENT

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# DURABILITY OF P. C. CONCRETE AS AFFECTED BY AGGREGATE SIZE, CURING AND PROPORTIONS

## 1.0 INTRODUCTION

The durability of concrete is a most important aspect in pavement life. Deterioration of the interstate portland cement concrete pavement has prompted various studies of factors which may contribute to the durability.

Studies of cores taken from deteriorated areas indicated that the larger particles of coarse aggregate may contribute greatly to the problem. This indication was mainly due to the analysis of the cracking pattern which showed that most of the cracks passed through the larger aggregates and the larger aggregate particles were more cracked than the smaller particles.

## 2.0 PURPOSE

The purpose of this project is to determine if the size of the coarse aggregate has a bearing on the durability of freeze and thaw beams.

A secondary purpose of this project is to determine what effect the method of curing and proportions have on the durability of freeze and thaw beams.

## 3.0 MATERIALS

The Type I cement used in this project was a blend of 7 cements tested under Lab. No. AC3-5847.

The fine aggregate from Hallett's pit at Ames (Sp. G. 2.67) complied with the standard specification 4110.

The coarse aggregate, crushed limestone from Hopper Brothers of Weeping Water, Nebraska, (Sp. Gr. 2.66) was assigned Lab. No. AAC5-46.

The only admixture used was Ad Aire ACA5-32 for air entrainment.

## 4.0 LABORATORY PROCEDURE

The sample of coarse aggregate was obtained by the district materials personnel and submitted to the Materials Laboratory. The coarse aggregate was screened and rebuilt to the following gradation for the 1-1/2" and 1/2" coarse aggregate sizes.

| 1-1/2" C. Agg. | | 1/2" C. Agg. | |
|---|---|---|---|
| Sieve No. | % Passing | Sieve No. | % Passing |
| 1-1/2" | 100 | | |
| 1" | 89 | 1/2" | 100 |
| 3/4" | 58 | 3/8" | 50 |
| 1/2" | 33 | 4 | 0 |
| 3/8" | 15 | | |
| 4 | 0 | | |

## 4.1 MIXING AND MOLDING PROCEDURE

The fine aggregate was dried prior to mixing and at the time of mixing had an absorption of 0.5%. The coarse aggregate was soaked for 24 hours and then spread out and dried to a saturated surface dry condition for mixing.

The sand and cement were proportioned and mixed for one minute followed by the addition of the coarse aggregate and an additional one minute of mixing. After this mixing of the dry materials, the air entraining agent was added in 5 to 10 pounds of water followed by enough additional water added during 3 minutes of wet mixing to yield approximately a 2-1/2 inch slump.

Three 4"x4"x18" beams were molded, using steel molds, for each mix proportion (C-3, C-5, C-7 as shown in Table I) coarse aggregate size (1-1/2" & 1/2"), and method of cure (9 methods). The beams were molded in two lifts using a platform vibrator for consolidation.

4.2 CURING METHODS

Method 1. Cover beams with a polyethelyne film (1 mil thickness) for a minimum of 20 hours after molding followed by 7 days in the moist room (ASTM C-511) and one day in a water bath at 40°F.

Method 2. Curing was the same as method one except for 27 days in the moist room.

Method 3. Curing was the same as method one except for 89 days in the moist room.

Method 4. Cover beams with a polyethelyne film (1 mil thickness) for a minimum of 20 hours followed by 7 days in the moist room, then 48 hours in a 200°F. oven and allowed to cool to room temperature before being put in the 40°F. water bath for one day.

Method 5. Curing was the same as method No. 4 except for 27 days in the moist room.

Method 6. Curing was the same as method No. 4 except for 89 days in the moist room.

Method 7. Four hours after mixing, steam curing of the beams was started and continued for 18 hours at 150°F. (heated from 80° to 150°F. in 2 - 4 hours) followed by a cool down period. This was followed by 7 days in the moist room and one day in the 40°F. water bath.

Method 8. Curing was the same as method No. 7 except for 27 days in the moist room.

Method 9. Curing was the same as method No. 7 except for 89 days in the moist room.

## 4.3 TESTING PROCEDURE

Testing was conducted as set forth in ASTM C-291 with the following exceptions:

1. Specimen length was 18"
2. Beam modulus and lengths read once per week (56 cycles)
3. Beam not randomly placed in freezer
4. Beams not turned end for end (One end always down)

## 5.0 INTERPRETATION OF RESULTS

The durability factors and growth in per cent are tabulated in Table II. The durability test (freezing and thawing ASTM C-291) was continued for 300 cycles or until the dynamic modulus was reduced to 60% of the original dynamic modulus whichever occurred first.

Figure No. 1 is a comparison of the durability factors obtained from a C-3 mix. The 1/2" coarse aggregate exhibits a higher durability factor than the 1-1/2" coarse aggregate for all methods of cure. The C-3 mix contains 36% coarse aggregate (55% of the total Aggregate Volume) and therefore is a greater test of the durability of the coarse aggregate than are the C-5 and C-7 mixes containing a lesser percentage of coarse aggregate.

For the C-5 mix in figure No. 2, the 1/2" size coarse aggregate excels in methods of cure 1-3 and 7-9, with about equal performance in methods 4-6. The C-5 mix contains 29% coarse aggregate (45% of the total aggregate volume).

Figure No. 3 is a comparison of the C-7 mix performance and the 1/2" coarse aggregate again excels for methods 1-3 and 9. The 1-1/2" size coarse aggregate exhibits a slight superiority for methods 4-8. The C-7 mix contains only 21% coarse aggregate (35% of the total aggregate volume) therefore making the durability factor less dependent on the coarse aggregate and more dependent on the sand-cement mortar.

There are 9 methods of cure shown for each mix No. (Figures 1, 2 & 3) and aggregate size. Methods 4, 5 & 6 yielded the highest durability and methods 7 and 8 had durabilities which were higher than methods 1 and 2. The poorest durability was obtained when curing by method 9 using 1-1/2" size coarse aggregate. If the three systems of curing are considered independently, a longer period of moist curing results in lower durability. This trend is shown in all three mixes.

Mix proportion C-7 had the best durabilities and C-3 had the poorest durabilities.

## 6.0 SUMMARY

In conclusion, the results indicate that the size of the coarse aggregate definitely has a bearing on the durability factor obtained from freeze and thaw beams. The 1/2" size coarse aggregate produces beams with better durability than the 1-1/2" size. The C-3 mix leaves no question of the higher durability of the 1/2" size aggregate with the C-5 and C-7 mixes showing the same trend to a lesser degree.

The curing methods also exhibit a definite bearing on the durability of freeze and thaw beams. A period of oven curing, after initial moist curing, definitely increases the durability. The longer period of moist curing decreases the durability of test specimens.

Mix proportion C-7 yields better durability than the other proportions, with mix proportion C-3 showing the poorest durability.

TABLE I

Absolute Volume and Batch Weights

| Material | C-3 Absolute Volume | C-3 Weights 1 cu.yd. | C-5 Absolute Volume | C-5 Weights 1 cu.yd. | C-7* Absolute Volume | C-7* Weights 1 cu.yd. |
|---|---|---|---|---|---|---|
| Cement | .114172 | 604 | .122867 | 650 | .138613 | 733 |
| Water | .163840 | 276 | .176318 | 297 | .184863 | 311 |
| Air | .060000 | ** | .060000 | ** | .060000 | ** |
| Fine Aggregate | .297395 | 1338 | .352948 | 1588 | .409782 | 1843 |
| Coarse Aggregate | .364593 | 1634 | .287867 | 1290 | .206742 | 927 |

*The Standard Specifications do not include a C-7 mix; this mix was designed by the Special Investigations Section.

**Air agent at 1 fluid ounce per sack of cement.

TABLE NO. II

Durability Factor and Growth of Beams

| | | #4 to 1-1/2" Coarse Aggregate | | | | | | #4 to 1/2" Coarse Aggregate | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C-3 Mix Proportions | | C-5 Mix Proportions | | C-7 Mix Proportions | | C-3 Mix Proportions | | C-5 Mix Proportions | | C-7 Mix Proportions | |
| Cure No. | Type of Cure | Growth % | D.F. | Growth % | D.F. | Growth % | D.F. | Growth % | D.F. | Growth % | D.F. | Growth % | D.F. |
| 1 | 1 day in mold covered, 7 days M.R., 1 day cooler | 2 Beams .018 | 97 | .020 | 97 | .015 | 97 | 2 Beams .009 | 99 | .011 | 97 | .009 | 100 |
| 2 | 1 day in mold covered, 27 days M.R., 1 day cooler | .050 | 82 | .039 | 84 | .032 | 90 | .014 | 95 | .017 | 94 | .023 | 96 |
| 3 | 1 day in mold covered, 89 days M.R., 1 day in cooler | .091 | 66 | .054 | 84 | .055 | 79 | .025 | 90 | .046 | 86 | .021 | 94 |
| 4 | 1 day mold, 7 day M.R., 2 day 200° oven 1 day cooler | .024 | 110 | .013 | 108 | .012 | 116 | .009 | 111 | .006<br>.014 | 111<br>112 | .009 | 112 |
| 5 | 1 day mold, 27 day M.R., 2 day 200° oven, 1 day cooler | .017 | 110 | .013 | 110 | .014 | 110 | .014 | 112 | .011 | 109 | .017 | 110 |
| 6 | 1 day mold, 89 day M.R., 2 day 200° oven 1 day cooler | .015 | 105 | .020 | 106 | .015 | 110 | .011 | 108 | .015 | 104 | .018 | 106 |
| 7 | 18 hr. steam, 7 day M.R., 1 day cooler | .018 | 100 | .013 | 104 | .014 | 106 | .004 | 103 | .010 | 102 | .004 | 103 |
| 8 | 18 hr. steam, 27 day M.R., 1 day cooler | .041 | 91 | .019 | 98 | .015 | 102 | .010 | 100 | .008 | 102 | .014 | 100 |
| 9 | 18 hr. steam, 89 day M.R., 1 day cooler | 3 Beams 240 Cycles .111 | 48 | 3 Beams 276 Cycles .137 | 55 | .087 | 76 | .043 | 92 | .059 | 88 | .013 | 98 |

Note: All values for 3 beams and 300 cycles unless noted.

Figure No. 1

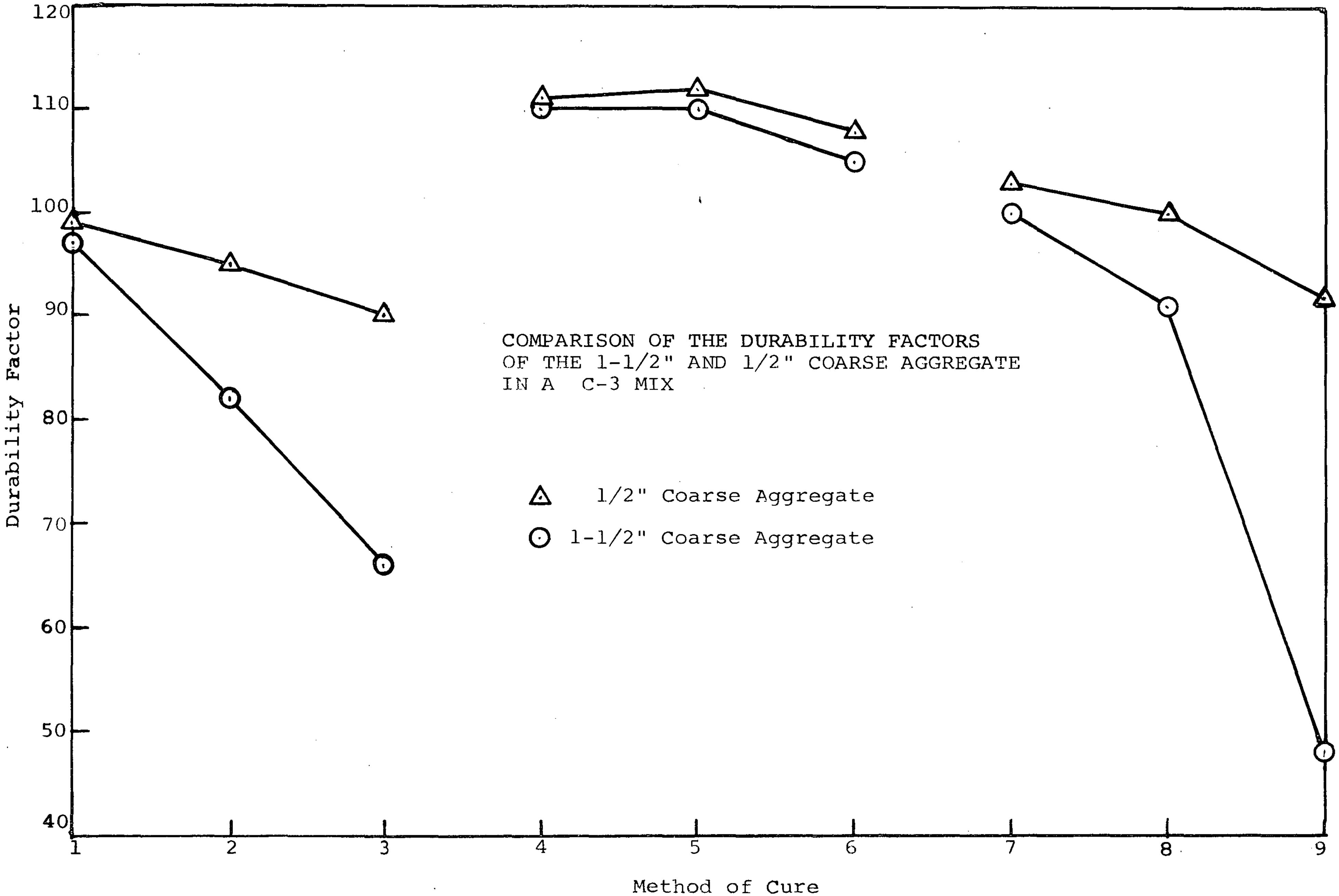

COMPARISON OF THE DURABILITY FACTORS
OF THE 1-1/2" AND 1/2" COARSE AGGREGATE
IN A C-3 MIX
1/2" Coarse Aggregate
1-1/2" Coarse Aggregate
Durability Factor
Method of Cure
120
110
100
90
80
70
60
50
40
1
2
3
4
5
6
7
8
9

Figure No. 2

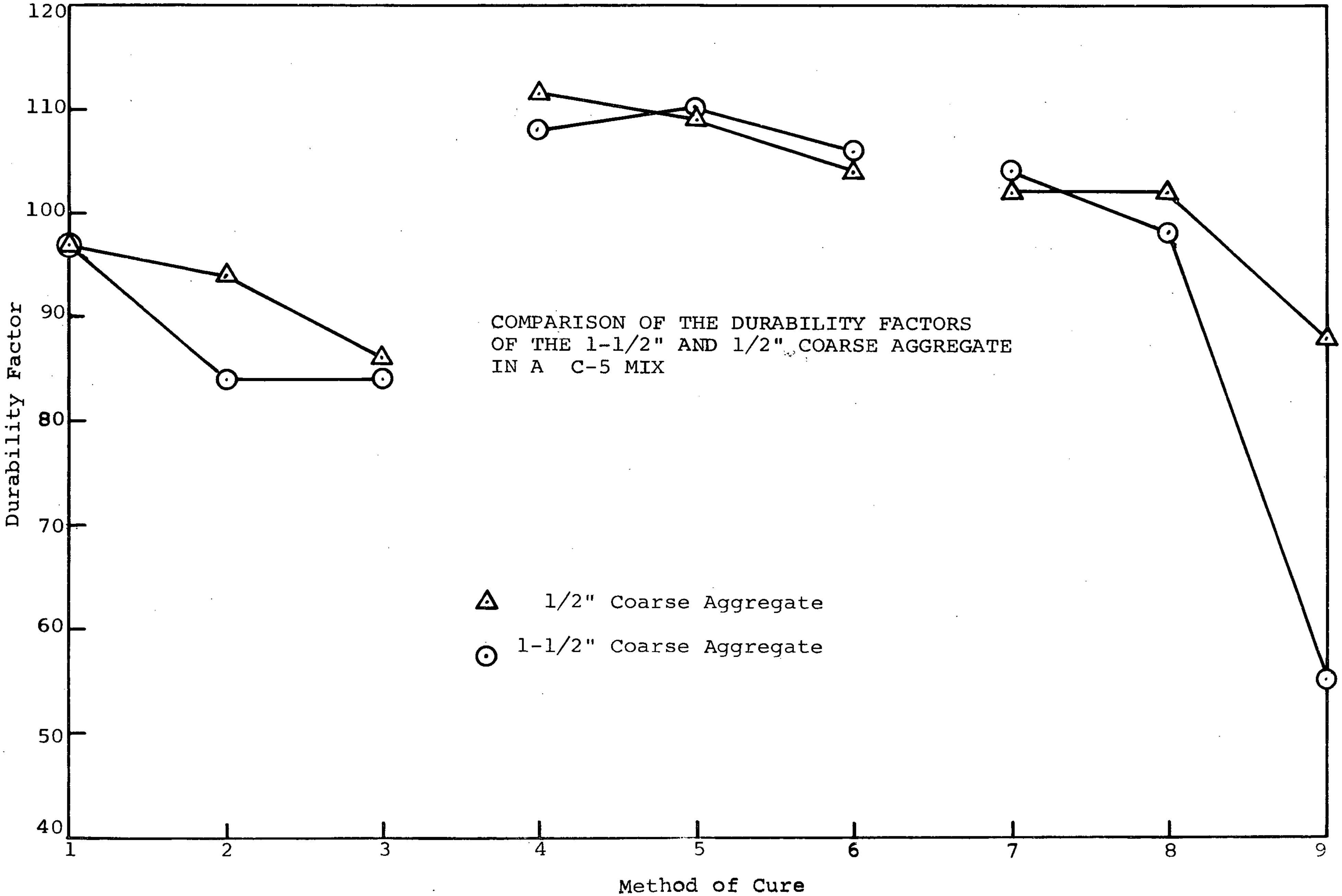
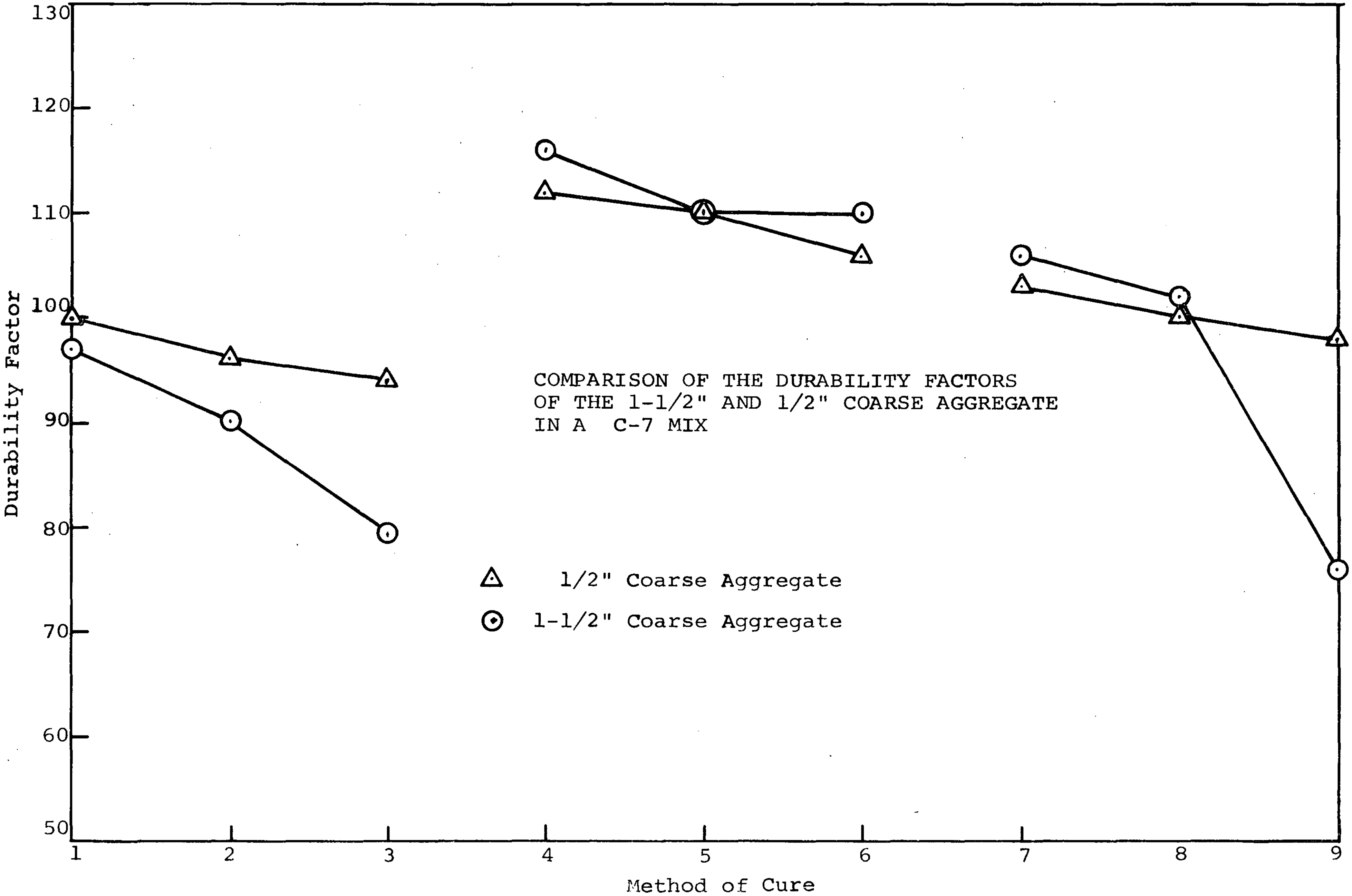

COMPARISON OF THE DURABILITY FACTORS
OF THE 1-1/2" AND 1/2" COARSE AGGREGATE
IN A C-5 MIX
1/2" Coarse Aggregate
1-1/2" Coarse Aggregate
Durability Factor
120
110
100
90
80
70
60
50
40
1
2
3
4
5
6
7
8
9
Method of Cure

Figure No. 3


130
120
110
100
90
80
70
60
50
Durability Factor
COMPARISON OF THE DURABILITY FACTORS
OF THE 1-1/2" AND 1/2" COARSE AGGREGATE
IN A C-7 MIX
1/2" Coarse Aggregate
1-1/2" Coarse Aggregate
1
2
3
4
5
6
7
8
9
Method of Cure