



COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
FRANKFORT

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ADDRESS REPLY TO
DEPARTMENT OF HIGHWAYS
MATERIALS RESEARCH LABORATORY
132 GRAHAM AVENUE
LEXINGTON 29, KENTUCKY

Ward J. Oates
COMMISSIONER OF HIGHWAYS

B. 3. 6.
D. 1. 7.

MEMO TO: D. V. Terrell
Director of Research

The attached report, "Lean Concretes Using Kentucky's Dense-Graded Aggregate (Portland Cement and SS-1 Emulsified Asphalt)", represents a laboratory investigation on the effects of the 2 cements on dense-graded aggregate.

I believe, with the design data and particularly mixture properties as shown in this report, that we should proceed with plans to build a test pavement incorporating at least these 2 cementing agents. The treated dense-graded aggregate should be evaluated as a base type. It may have merit for a component of high type shoulder construction.

We are studying with interest the use of slip form pavers for placing portland cement treated dense-graded aggregate base courses.

Respectfully submitted

A handwritten signature in cursive script, appearing to read "W. B. Drake".

W. B. Drake
Associate Director of Research

WBD:dl

Enc.

cc: Research Committee members
Bureau of Public Roads

Commonwealth of Kentucky
Department of Highways

LEAN CONCRETES USING KENTUCKY'S DENSE GRADED AGGREGATE
(Portland Cement and SS-1 Emulsified Asphalt)

by

James H. Havens, Assistant Director of Research

and

Milton Evans, Jr., Research Engineer

(Presented to Kentucky Department of Highways, Research
Committee, February 16, 1959)

Highway Materials Research Laboratory
Lexington, Kentucky

June, 1959

INTRODUCTION

Since the development of dense-graded aggregate base in Kentucky about 1952 (1)(2)(3), there have been various conjectures about "auto-cementations" or "setting" of these materials when compacted and cured (4)(5). In some cases, particularly when the material was limestone, they have developed rather surprising strengths, in the field as well as in the laboratory. Such displays of strength seem to be directly associated with curing (slow drying) and the possibility of re-deposition of small amounts of dissolved calcium carbonate as cement. If this is so, it might be surmised that bases which have not been "fixed" by curing and drying before surfacing may never acquire strength by virtue of auto-cementation, or may lose it on re-wetting. It may be surmised, likewise, that unless auto-cementation occurs, the supporting ability of the base must be governed by the binding power of whatever moisture is present and by virtue of physical confinement. Thus, the idea of deliberately introducing cement is quite logical if inherent strength is to be assured.

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- (1) "Report No. 1 on a Limestone-Calcium Chloride Stabilized base", by W. B. Drake, Reports of the HMRL, Vol. VII, Part IV, p 75-106 Aug. 1952.
 - (2) "Report No. 1 on a Water-Bound Dense-Graded Aggregate Base, Casey County Project F 505(1), Phil-Pine Grove Road", by E. G. Williams, Reports of the HMRL, Vol. VIII, Part III, p 286-308, 1953.
 - (3) "Inspection of Full Depth Modified Dense-Graded Aggregate Base, (Ten. Dept. of Highways Project No. 1-001-5(27))", by W. B. Drake, Reports of the HMRL, Vol. IX, Part III, p 197-213, Dec. 1954.
 - (4) "An Investigation of the Binding Properties of Limestone Dust", by W. E. Howard and E. G. Williams, Reports of the HMRL, Vol. IX, Part III, p 283-345, Dec. 1954.
 - (5) "A Study of the Effects of Gradation of the Strength Properties of a Dense Aggregate Base Mixture", J. W. Fehr, Master's Thesis, UK, 1957.

The desirabilities of dense-graded aggregate are evident in the ease with which it is manipulated, placed, compacted, shaped, and smoothed to grade. When properly confined above and below and at the sides, as in a base overlain by significant thicknesses of pavement, there seems to be little, if any, need for cemented-strength. However, inherent or cemented strength may be essential where not overlain by significant thicknesses of other pavement. For instance, considerable thought has been given to the possibility that stabilized (cemented) dense-graded aggregates, with or without light surface treatment, might serve as paving system for shoulders on interstate roads and possibly as initial treatments or bases on some rural and secondary roads.

With these possibilities in mind, a series of exploratory experiments were performed in the laboratory on various blends of portland cement (Type I) and dense-graded aggregate and on blends of asphaltic-type cements (SS-1) and dense-graded aggregate. The first objective, of course, was to delineate basic principles in the design of such mixtures and to examine any extraneous factors that may be involved. The Division of Materials made a rather extensive study of SS-1 mixes and a preliminary series of tests on portland cement mixes. This report is, therefore, supplementary to that priority.

In the work reported here, it was presumed that SS-1 was the type of asphaltic material most amenable to use with dense-graded aggregate, that the materials could be best blended by plant mixing,

(6) Memo Report to A. O. Neiser on "Low Strength Concrete", by J. A. Bitterman, May 20, 1958.

and that the mixture would be placed with pavers or by blade-spread-ing and rolling. It was also presumed that the portland cement blends would be plant mixed. However, two possibilities existed for the method of placement. For instance, it would be desirable in many respects to also place portland cement mixes with a paver (7) or by blade spread-ing and rolling (compaction at or near optimum moisture content). Al-ternatively, portland cement blends might well be placed as normal "slump" concrete. The later method, of course, would probably re-quire the use of conventional forms. Thus, two types of portland cement blends needed to be investigated.

It is of interest, of course, from a more general point of view to compare the present idea, at least in principle, with those of soil-cement stabilization, bituminous stabilization of fine-grained and granular soils, as well as lean concretes. In particular, lean concretes using normal coarse aggregates and otherwise conventional mixture designs, air-entrainment, slump, etc., offer a third possibility for base construction. Although a detailed comparison of these is some-what beyond the scope of this report, it may suffice here to call atten-tion to the fact that most soils may be successfully stabilized with 5-15% portland cement by volume ($5-15\% \times 27 \text{ ft}^3 = 1.35 \text{ to } 7.5 \text{ sacks/ yd}^3$). Thus, the cement requirements for lean concretes whether made with DGA or possibly No. 36 stone and sand may be comparable to that required to stabilize the better graded soils. In 1950, an experimental

(7) As a matter of interest, attention is directed to: "Traveling Forms for Paving...", Fred F. Loy, District Engineer, Portland Cement Association, Modern Highways, Sept. 1958.

lean concrete base was constructed on US 60, Winchester-Mt. Sterling (8)(9), which used the following mix-design factors:

Cement factor	3.5 sacks/yd ³
Ratio of FA to total	34-38%
Max. free water . . .	9.75 gal/sack
% air	3 to 6
Type cement	I-A
CA	No. 36 limestone
FA	O.R. sand

The average mix-water during construction was 8.5 gal/sack. Flexural strengths and compressive strengths (28-days) averaged somewhat higher than 400 psi and 1800 psi respectively.

VOLUMETRIC CONSIDERATIONS IN DESIGN

Dense-graded aggregate is normally compacted to 85% solid volume ($62.4 \times 2.72 = 171 \text{ lbs/ft}^3$; $171 \times 85\% = 145 \text{ lbs/ft}^3$ compacted unit dry wt). Usually about 5-1/2 to 6% water (or liquid such as SS-1 or SS-1 plus water) by weight of dry aggregate is optimum for compaction ($145 \times 6\% = 8.7 \text{ lbs H}_2\text{O}$; $8.7/62.4 = .14 \text{ ft}^3$). At 85% solid volume of aggregate, 0.15 ft³ of bulk cement would be indicated as the maximum allowable assuming that no bulking occurs ($0.15 \text{ ft}^3 \times 0.48 \text{ ft}^3$ solid vol. per sack of cement = 0.072 ft^3 ; $0.85 \text{ ft}^3 + 0.072 \text{ ft}^3 = 92.2\%$ solid vol. of aggregate + cement; $0.15 \times 27 = 4.05 \text{ bags/yd}^3$ C.F.; and 7.8% water by vol. or $0.078 \text{ ft}^3 \times 7.48 \text{ gal/ft}^3 = 0.584 \text{ gal/ft}^3$; $0.584 \times 27 = 15.7 \text{ gal/yd}^3$ or 3.9 gal/sack of cement). However, the optimum

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- (8) Collier, S. T.; "Report No. 1 on an Investigation of Lean Concrete Mixes as Base Courses for Bituminous Surfaces," Reports of the Highway Materials Research Laboratory, Vol. VI, Part I, 1951.
 - (9) Sawyer, D. H.; "Report No. 2 on an Investigation of Lean Concrete Mixes as Base Courses for Bituminous Surfaces," Reports of the Highway Materials Research Laboratory, Vol. VIII, Part II, 1953.

water for compaction remains approximately constant (about 5-1/2 to 6%) regardless of the cement factor. Likewise, water requirements for workability (slump) remain fairly constant (about 35 gal/yd³) regardless of cement factor (35 gal/yd³ ÷ 4.05 = 8.65 gal/sack of cement). Thus, 15.7 gal/yd³ is approximately half the amount needed for optimum compaction, and this amount is only 5 to 10 gal/yd³ short of the amount needed for slump consistency. To include the additional amounts (15 to 25 gal.) required by these conditions would involve bulking and increased yields.

Design by Moisture-Density Tests

Alternatively, if 5-1/2 to 6% (say 5.75%) water by weight of dry aggregate is assumed or established by moisture-density tests and 146 lbs/ft³ is assumed to be an approximate dry unit weight (based on Sp G of limestone aggregate as 2.72 and cement as 3.14, total dry wt/yd³ of 4000 lbs; 3-1/2-bag mix; avg. Sp G = 339/4000 x 3.14 + 4000-339/4000 x 2.72 = 0.258 + 2.49 = 2.75), 146 x 5.75% = 8.4 lbs water/ft³ or 8.4/62.4 = 0.135 ft³. Then 0.135 x 27 = 3.64 ft³ of water/yd³.

$$\begin{array}{r}
 3.64 \text{ ft}^3 \text{ water/yd}^3 \\
 +1.57 \text{ ft}^3 \text{ solid vol. 3-1/2 bags cement} \\
 \hline
 5.21 \text{ vol. water + cement} \\
 +0.41 \text{ vol. void assuming 1.5\% air, entrapped} \\
 \hline
 5.62 \text{ ft}^3 \text{ vol. water, cement, and air}
 \end{array}$$

$$\begin{array}{r}
 27.00 - 5.62 = 21.38 \text{ ft}^3, \text{ vol. of DGA} \\
 21.38 \times 62.4 \times 2.72 = 3620 \text{ lbs DGA/yd}^3
 \end{array}$$

$$\begin{array}{r}
 3620 \text{ lbs DGA} \\
 +339 \text{ lbs cement} \\
 \hline
 3959 \text{ lbs dry wt/yd}^3
 \end{array}$$

$$\begin{array}{r}
 \text{Wet weight} = 3959 + 3.64 \times 62.4 = 4186 \text{ lbs} \\
 \text{W/C} = 3.64 \times 7.48/3.5 = 7.8 \text{ gal/sack} \\
 \text{Free water} = 27.2 \text{ gal/yd}^3
 \end{array}$$

Correction for Air-Entrainment

Theoretically, if it were possible to entrain significant amounts of air in the above mix and to retain it despite compaction, the air (say 1.5% entrapped + 4.5% entrained = 6% total) would displace DGA only ($6\% \times 27 = 1.62 \text{ ft}^3$). Since water and cement would give a combined volume of 5.21 ft^3 ,

$$\begin{array}{r} 5.21 \text{ ft}^3 \text{ water + cement} \\ + 1.64 \text{ ft}^3 \text{ total air} \\ \hline 6.85 \text{ ft}^3 \text{ water + cement + air} \end{array}$$

$$\begin{array}{l} 27.00 - 6.85 = 20.15 \text{ ft}^3 \text{ vol. DGA} \\ 20.15 \times 62.4 \times 2.72 = 3420 \text{ lbs DGA/yd}^3 \end{array}$$

$$\begin{array}{r} 3420 \text{ lbs DGA/yd}^3 \\ + 339 \text{ lbs cement} \\ \hline 3759 \text{ lbs dry wt/yd}^3 \end{array}$$

Design for Slump

Although the amount of mixing water to produce slump consistency appears to remain fairly constant (30 to 40 gal/yd³) regardless of cement factor, it seems advisable to run a test series on blends of the particular aggregate and at various cement factors and air contents. Yields should be easily calculated by thus fixing the amounts of air, water and cement and finding the volume of DGA by difference.

Design Using Asphaltic Emulsion (SS-1)

A general criterion for design using SS-1 asphaltic emulsion may be derived similarly by slight modification of the Marshall Stability criterion. Presumably, the optimum M.C. of DGA, as determined by Proctor tests is closely analogous to the optimum asphalt content of bituminous mixes as determined by Marshall compaction. While it is recognized that there may be differences between the two

methods with respect to compactive forces and the lubricating characteristics of asphalt cements as compared to water, the asphaltic emulsion (SS-1), which is dilutable with water, would not be expected to inhibit compaction in either method. Thus, an optimum liquid content, whether consisting of plain water, emulsion, or diluted emulsion, may be determined approximately by either method of compaction; and the resulting density of the DGA should approach or equal the 85% solid volume requirement now applicable to DGA.

Assuming, then, that it is desired to prepare a mixture containing 3% base asphalt (SS-1 contains approximately 60% base asphalt and 40% water), the amount of emulsion required would be $3\%/0.60 = 5\%$. Therefore, if 6% liquid is found to be optimum for compaction, it would be necessary to add 1% water to the mixture or else to dilute the emulsion to the extent that: $3\%/X = 6\%$; $X = 50\%$ base asphalt; then, $5:60 :: X : 100$, and $60X = 50 \times 100$, $X = 83.5\%$ SS-1, and the dilution water = 16.5%.

Actually, it is foreseeable that unless the aggregates were pre-dampened, absorption of water by the aggregate may cause premature breaking of the emulsion and also rob the mixture of free water. Pre-dampening the aggregate would, therefore, enhance the mixing operation, provided, of course, that any free water or surface water on the aggregate is determined, and provided that the total free liquid content does not exceed the indicated optimum.

The maximum asphalt content would be limited by the indicated optimum liquid content for compaction. Optimum asphalt content, however, may be indicated by factors such as resistance to shear,

strength, or stability. Minimum asphalt content may be indicated by some strength test and resistance to soaking in water.

SUMMARY OF LABORATORY WORK ON P.C. MIXES

In anticipation of the possibility of placing and compacting the portland cement mixes at or near optimum moisture content, moisture density curves were derived for dry blends of DGA (10) and cement, in proportions approximating 2-, 3- and 4-bag mixes. By Proctor compaction, the indicated optimums ranged between 5.5 and 6.0% and by Marshall compaction were between 5.0 and 6.0%. Attempts to prepare test beams and cylinders by ramming and tamping these mixtures into molds were rather unsuccessful. Even though considerable effort was devoted to this part of the work, the specimens so prepared were usually honeycombed and rather un-uniform; and in no case was it possible to produce a troweled finish on them. Although, several such mixes were prepared; it was not possible to evaluate them reliably in terms of beam and cylinder strengths or by F & T durability.

Alternatively, it was found that satisfactory specimens could be prepared by ramming and tamping (Figs. 1 & 2) at water contents considerably higher than optimum but slightly lower than that necessary to give impending slump. This, essentially, was the method used to prepare the zero- or no-slump concretes, Series I and III, reported in Table I.

(10) Aggregate source: Jessamine and Benson Members of Lexington Series, See Young, Havens and Gregg; "A Laboratory Investigation of the Mineralogical, Chemical and Physical Properties of Limestone Aggregates," HRB Abstracts, Vol. 19, June 1949.

No-Slump, A/E Mixes (Series IV)

Attempts to entrain air in mixes at optimum water contents were altogether unsuccessful. Realizing, then, that there was insufficient free water in the mixes to form air bubbles, water contents were increased to impending slump. Here, small amounts of air could be entrained by the usual method of mixing, but it was usually dissipated after ramming and tamping in the molds. It was subsequently found, however, that by first mixing the cement, water, and air-entraining agent, a foamy slurry could be formed and that much of this air could be retained after mixing with damp aggregate and even after ramming and tamping the concrete in the molds. This, essentially, was the method used to prepare the no-slump, A/E mixes reported as Series IV in Table I.

A/E, Slump Mixes (Series II)

No difficulties were encountered in mixing, entraining air, or in preparing specimens from mixes of normal slump consistency. The water contents used were simply those necessary to give the desired slump. These mixes are reported as Series II in Table I.

Strengths and Durabilities

Both 7- and 28-day flexural and compressive strengths for the four series of mixes are given in Table I. All specimens were moist-cured in the usual way.

For durability testing, beam specimens were moist-cured 14 days, soaked 24 hours, and then subjected to freeze-thaw (ASTM C-291).

In Table I, it is apparent that 2-bag mixes have very low strengths and very little resistance to F & T. Strengths, of course,

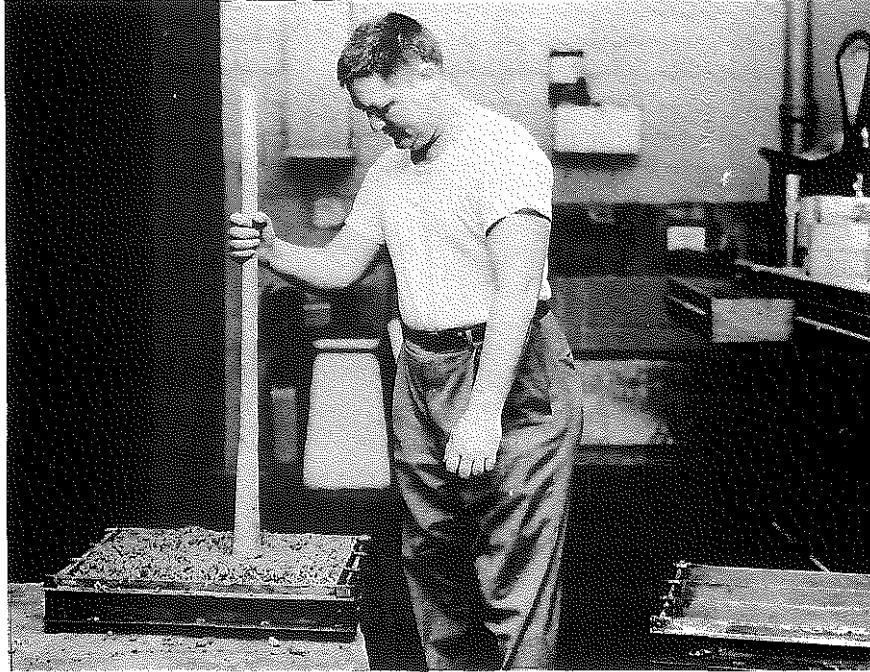


Fig. 1: Ramming and Tamping No-Slump, Lean Concrete in Molds.

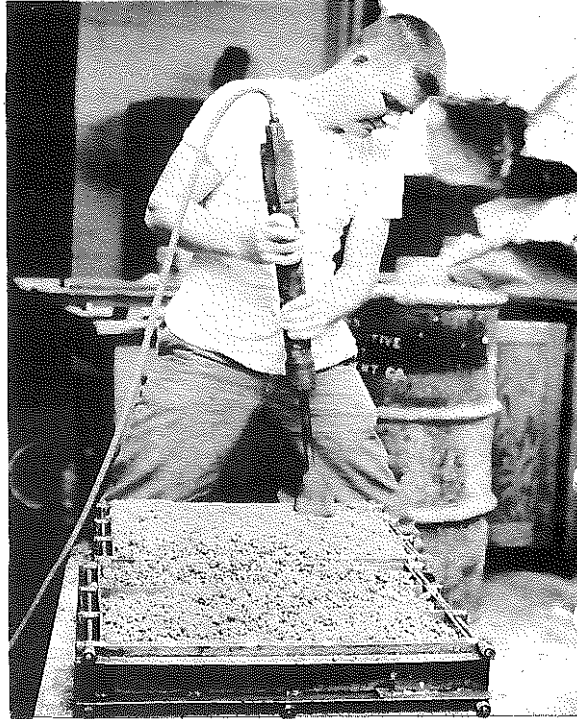


Fig. 2: Ramming and Tamping No-Slump, Lean Concrete in Molds with Air Hammer.

increase with increased cement factor as expected by the usual concept of the relationship between strengths and cement factor. It is quite obvious, too, that air entrainment is highly essential to F & T durability (also, see Fig. 3) and that 3 bags/yd³ is about the minimum practicable cement factor if F & T durability is to be assured.

Although the calculated values are not given in Table I, it is apparent that the A/E, 3-in. slump mixes, Series II, required approximately 40 gal/yd³ or 9.2% water by weight. This exceeds the indicated optimum for compaction (without air) by about 3%; whereas the no-slump, compacted mixes exceeded optimum by 1 to 4%, but this difference decreases with increased cement factor.

TABLE 1: TEST RESULTS ON DENSE GRADED AGGREGATE CONCRETE

C. F. (bags)	Method of Placement	Slump in.	% Air	Unit Wt. (lb/ft ³)	Opt. M. C.	Theo. W/C based on Opt. (gal/bag)	Actual W/C gal/bag	F & T Cycles to Failure	Flex. Str.		Comp. Str.	
					by Proctor %				7	28	7	28
<u>Series I: Non A/E (Compacted at or near impending slump)</u>												
2	Rammed and tamped	0	2.0	148.0	5.95	12.47	20.10	10	180	266	551	972
3	in place by hand with	0	2.3	147.2	5.54	7.99	10.92	29	420	553	1531	3233
4	a 2-1/4" diameter	0	1.7	149.2	6.46	7.13	8.69	35	640	647	2412	3143
5	wooden rod	0	1.4	148.8	-	-	6.92	46	713	807	3663	4323
<u>Series II: A/E (Slump)</u>												
2	Rodded in place	2-3/4	8.0	134.8	5.95	12.47	20.31	10	35	80	171	224
3	in the conventional	3	8.6	133.6	5.54	7.99	13.60	300+	150	246	543	831
4	manner with a 5/8"	3	8.8	133.2	6.46	7.13	10.42	300+	300	440	1032	1722
5	bullet nosed rod	2-1/2	6.0	138.8	-	-	8.74	300+	486	593	2085	2572
<u>Series III: Non A/E (Compacted at or near impending slump)</u>												
3	Tamped in place	0	1.0	152.0	5.54	7.99	11.32	29	453	606	1781	2386
4	with a 70 psi air	0	1.0	151.6	6.46	7.13	9.14	20	580	760	2530	3365
5	tamper using a 3" dia. tamping head	0	1.4	150.8	-	-	6.21	25	700	713	3539	4565
<u>Series IV: A/E (Compacted at or near impending slump)</u>												
3	Rammed and tamped	0	5.5	142.8	5.54	7.99	11.21	300+	327	420	1306	1775
4	in place by hand	0	6.0	142.4	6.46	7.13	9.38	300+	513	580	1929	2773
5	with a 2-1/4" dia. wooden rod	0	5.0	144.8	-	-	6.21	300+	580	720	2867	3403

Note: All test data represents average of three specimens.
Aggregate source: Jessamine and Benson, Lexington Series
Cement: Type I



Fig. 3: Photograph Showing DGA Concrete Specimens in F & T Chamber after about 25 Cycles. Specimens marked 2- and 4-AE are air-entrained concretes containing 2 and 4 bags of Type I cement, respectively. Deteriorated specimens are non-air concretes containing 2 and 3 bags of cement. Note: 2 specimens of non-air concretes containing 4 bags of cement per cu. yd. (center and lower right) remained in relatively good condition at this stage in the testing.

SUMMARY OF LABORATORY WORK ON SS-1 MIXES

It was anticipated that the dominate factor in the evaluation of the SS-1 mixes would be the rate and degree to which curing would progress under various conditions. Likewise, it was expected that "cemented strength" would not be fully manifested until the asphalt had become completely "fixed" by curing and drying. Having once achieved fixation of the asphalt, a high level of strength should persist after re-wetting and soaking. Hence, the primary objective in this phase of the work was to establish the minimum asphalt content and curing that would assure a high order of strength and water-resistance.

Preliminary Curing Tests

Marshall-type specimens were prepared using 2, 3, and 4% SS-1 and enough water to provide a total liquid content of approximately 6% (approximately optimum). These specimens were cured in various ways and then tested for stability. The data derived therefrom are summarized in Table 2, and it is apparent therein that those curing conditions most favorable to drying resulted in the highest stabilities. It is also apparent that with increasing asphalt contents there was a commensurate loss in stability. While the losses there may be related to the fact that higher percentages of asphalt emulsion would require more rigorous curing in order to impart ultimate strength to the specimens, it is generally understood that this type of loss is characteristic of mixes having asphalt contents higher than optimum. This point of view would indicate that optimum would be rather close to 2%. However, from the standpoint of resistance to water, asphalt contents between 2 and 3% may prove to be more advantageous.

TABLE 2: Preliminary Curing Tests on SS-1 Mixes (Marshall Type Test Series)

Curing Condition	% SS-1 Added	M.C. as Tested	Stability (lbs.)	Flow	Dry Density lbs/ou.ft.	% Voids Total mix	% Voids Agg. Only	% Voids Filled W. ASP.
In molds 1 day at room temp., tested at room temp.	2	----	1027	23	142.3	14.2	16.9	16.0*
	3	----	1100	22	140.7	14.6	18.6	21.8*
	3	----	578	16	139.8	14.5	18.5	21.6**
	4	----	555	20	137.6	15.6	20.8	25.4*
In molds 1 day water bath 1 day, at room temp., tested at room temp.	2	(lost 25 - 40% of wt. in water bath.)			140.4	16.0	18.6	14.5*
	3				136.7	16.8	20.7	19.1*
	4				133.2	18.3	23.4	22.0*
In molds 1 day, water bath 3 days at room temp., tested 78°F.	2	5.5	552	12.5	140.7	15.4	18.1	14.5*
	3	6.2	462	10.0	138.5	15.5	19.8	19.3*
	4	5.5	362	9.5	137.6	15.5	20.9	25.5*
In molds 1 day, oven 1 day at 130°F, tested at 130°F.	2	1.5	2404	6	142.9	14.1	16.8	16.1*
	3	1.3	1448	-	141.0	14.4	18.4	21.7*
	4	1.3	1382	11	139.5	14.5	19.8	27.0*
In molds 1 day, room air 2 days, tested at room temp.	2	1.8	1479	15.0	146.6	12.6	15.4	17.9*
	3	3.8	985	13.0	138.2	16.1	20.0	19.6*
	4	3.0	1310	13.0	136.3	16.3	21.6	24.5*
	0	1.3	4811	10.5	142.6	16.0	16.0	0 *
0.5% CaCl ₂	0	2.1	2572	13.5	146.6	13.5	14.0	0 *
In molds 1 day, in air 5 days, immersed 1 day, tested at room temp.	2	2.3	1708	13.5	142.0	14.6	17.3	15.6*
	3	2.8	1842	17.0	141.1	14.3	18.9	22.3*
	3	2.8	2525	10.0	134.0	18.0	21.9	17.8**
	4	3.0	1530	15.5	137.3	15.7	21.0	25.2*
In molds 1 day, room air 1 day, tested at room temp.	3	-	1026	14.0	138.2	15.5	19.5	20.5**
In molds 1 day, air 1 day, water bath 1 day, tested at room temp.	3	-	2525	10.0	134.0	18.0	21.9	17.8**

* Benson and Jessamine Limestone, Central Rock Co.

** Tyrone and Oregon Limestone, Boonesboro.

Most of the results shown in Table 2 were obtained from mixes composed of Jessamine and Benson limestones but some of the specimens (indicated by double astericks) were composed of Tyrone and Oregon limestones. Likewise, the gradations of the two aggregates differed somewhat in the coarser sizes. The two gradations were as follows:

Jessamine & Benson		Tyrone & Oregon	
<u>Sieve</u>	<u>% Passing*</u>	<u>Sieve</u>	<u>% Passing**</u>
1"	100	1"	100
3/4"	85	3/4"	100
3/8"	65	1/2"	80
No. 4	50	3/8"	65
No. 10	37.5	No. 4	50
No. 16	31.5	No. 8	40
No. 40	22.5	No. 16	32
No. 50	20	No. 30	26
No. 100	12.5	No. 50	20.5
No. 200	10	No. 100	15.5
		No. 200	10

* Middle of Kentucky Spec.

** Corresponds to Fehr's No. 1 gradation (loc. cit.)

Triaxial Test Series

In order to compare the SS-1 mixes with "uncemented" mixes, in terms of cohesion and angle of internal friction; 4-in. diameter triaxial specimens were prepared with 3% SS-1, air-cured 6 days, and oven cured 1 day at 100°C before testing. The resulting values compared favorably with those obtained by Fehr (loc. cit.). A second set of specimens prepared and cured in the manner described above were immersed in water for 1 day prior to testing. These comparative data are as follows:

	<u>3% SS-1 (dry)</u>	<u>3% SS-1 (soaked)</u>	<u>Fehr's No. 1 (dry, no cement added)</u>
C	20 psi	12 psi	19 psi
φ	45°	2°	55.30°
M.C. (%)	0.45	5.10	1.68
Voids (%)	14.47	14.46	10.3

Comparison of SS-1 Mixes with P.C. Mixes by Freeze-Thaw (Marshall-Type Specimens)

Marshall-type specimens were prepared with the Jessamine and Benson aggregate and 3% SS-1, air-cured for a nominal period of 28 days, immersed in water for 1 day, and then subjected to freezing and thawing. Concurrently, similar specimens containing portland cement in the approximate proportions of a 3-bag mix were moist-cured 28 days, immersed for 1 day, and subjected to freeze-thaw. Fig. 4 graphically compares the two types of mixes from the standpoint of gain or loss in weight attending successive freeze-thaw cycles.

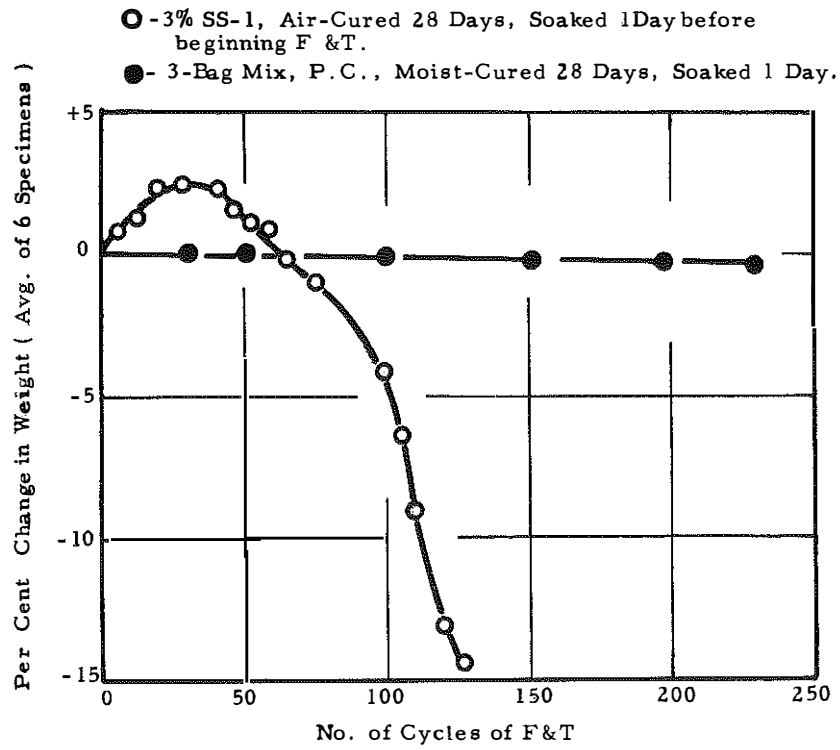


Fig. 4: Graph Showing Comparatively the Loss in Weight of DGA Mixes Subjected to Freeze-Thaw

DISCUSSION

Although the tests and results described were somewhat cursory and exploratory in nature, several general observations pertinent to the potential use of these materials may be made. For instance, none of the non-air-entrained portland cement mixes appears to have sufficient durability (resistance to F & T) to permit their use in exposed roadway surfacing. However, this should not prevent their use in the construction of bases, provided that they are overlain by sufficient thicknesses of other insulating pavement. This observation, of course, applies equally to the "slump" and "no slump" mixes. Since it was impossible to entrain significant amounts of air or to obtain a satisfactory surface finish in mixes prepared at optimum moisture contents and was possible only by resorting to a special mixing technique to entrain air in the "near-slump" mixes, the only mix that appears to be suitable for service as a pavement surface is the normal air-entrained slump-type mix. This, of course, would require the use of forms in construction, and any advantage that the DGA concrete might have over ordinary air-entrained lean concrete using conventional coarse aggregates would probably arise from the comparative costs of the two types of aggregates. The minimum practicable cement factor from the standpoint of durability appears to be 3 bags per cu. yd.

With regard to the SS-1 mixes, it does not appear that any extraneous difficulties would be encountered in placing and compacting the material on the road, with the possible exceptions that might arise from premature drying during hot, dry weather or from extreme moisture conditions caused by severe rainy weather. It is anticipated that SS-1 mixes of this type might find their most advantageous use in bases protected by other pavement surface courses of sufficient quality to prevent raveling under traffic.