An Evaluation of Gravels for Use in Lime-Fly Ash-Aggregate Composition

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This report presents the results of a laboratory study of the effects of gradation, hardness, soundness and silt-clay content of gravels when the gravels are used in lime-fly ash compositions. Durability and compressive strength tests are used as the basis for evaluation.

An attempt is made to establish a correlation between the variables and the anticipated field performance of the compositions.

Standard cylindrical specimens (4 in. dia. x 4.59 in. high) were prepared for different natural gravels mixed with optimum percentages of hydrated lime and fly ash. Specimens were also molded using one gravel to which varying amounts of fines were added along with the lime and fly ash. After suitable curing periods tests for unconfined compressive strength, freezing-thawing, durability, and moisture absorption were performed on the specimens.

Seven different gravels from widely scattered geographical areas were used in the investigation. The results have shown considerable variation in the performance of these materials when used in lime-fly ash-aggregate compositions.

● IT IS well known that the percentage and character of the fines (minus No. 200 sieve) in gravels are significant factors in the field performance of gravels for highway use. It is also known that the presence of fines has an effect on the resulting composition when the gravel is used in combination with lime and fly ash. This study was intended to provide qualitative and quantitative data on the effects of fines on the strength and durability of lime-fly ash-gravel compositions. In addition, it was desired to provide more general information by studying the strength and durability of the compositions when gravels from a variety of sources were used.

To make this evaluation, the effects of the following properties of a gravel have been considered: (a) effect of fines (minus No. 200 sieve) on the strength and durability of lime-fly ash-aggregate compositions; (b) effect of particle-size gradation on durability and strength (uniform vs well graded); (c) effect of the hardness and soundness of the individual gravel particles on strength and durability; and (d) effect of particle shape on strength and durability (round vs angular).

For the most part this last effect could not be evaluated because all but one of the gravels used contained well-rounded particles.

The investigation was divided into two parts: (a) the evaluation of the effect of fines on strength and durability of lime-fly ash-gravel compositions; and (b) a general evaluation of gravels, from different geographical locations, for use in lime-fly ash-gravel compositions.

At this time seven different gravels from widely scattered geographical locations have been used.

Each gravel has been completely analyzed and described. Standard cylindrical specimens have been made and tested by standard methods after suitable curing. Unconfined compressive strength, durability, frost susceptibility, and water absorption tests were performed.

MATERIALS USED

Natural Gravel or Sand

Gravels used in this investigation came from seven different areas located in New Jersey, Michigan, Ohio, New York, Illinois and Pennsylvania.

Each gravel has been investigated and identified by means of: (a) grain size—sieve analysis and hydrometer analysis; (b) particle shape; (c) geological origin and classification; (d) Atterberg limits; (e) hardness—using the ASTM Standard Method Designation c-131-55 test, the hardness is evaluated by the total loss of the sample in percent after 500 revolutions of the Los Angeles abrasion machine; and (f) soundness—using the ASTM Standard Method for soundness of aggregates by use of a sodium sulfate saturated solution. The soundness is evaluated as the total loss of the sample in percent after 5 cycles of alternate immersion and drying.

The results are given in Table 1 and the grain size curves are shown in Figure 1. A standard fly ash and hydrated lime were used.

TABLE 1
PROPERTIES OF THE NATURAL GRAVELS

Sample Desig.	Pit Location	Sieve Anal (% passing) 1 In.	No. 4	No 10	No 200	0.005 In.	Shape	Soundness, % Lost	Hardness Sample	Hardness % Lost	Uniform. Coeff, D_{60}/D_{10}	Remarks
G-101	N. J.	97	73	72	4	1	Round	8	A	48	5	Sandstone—20% Quartz—50% Quartzite—20% Conglomerate—10%
G-102	Pa.	93	71	62	23	10	¾ round	14.3	A	54 8	320	Felspathic sandstone (arkosic)
G-103	Ill.	100	73	38	6 6	1 4	Very round	6.15	D	41 8	22	
G-104	Mich.	96	69	48	3 8	1 4	Round	7.2	B	31.5	11	
G-105	Long Island, N Y	100	88	85	3	0 5	Round	4 6	No Test		2 3	Mere sand
G-106	Ohio	96	59	40	3 2	1 4	Round	7	A	26.0	10 7	Limestone—50% Mudstone—50%
G-107	N. J	77	59	53	1.4	—	Round	2 5	A	34	25 4	Arkose—25% Sandstone—25% Quartzite—25% Quartz + silica—25%

Manufactured Gravels

The so-called "manufactured gravels" were prepared by separating a natural gravel into batches and adding to each batch a different percentage of fines (soil passing No. 200 sieve). The percentage of fines that was added was varied in increments of 5 percent. In addition, one batch of manufactured gravel was prepared by removing all the soil passing the No. 200 sieve from the natural gravel. In this manner six different gravels, which varied only in percent of fines, were produced from the one natural gravel. The properties of these gravels are given in Table 2 and the grain size curves are shown in Figure 2.

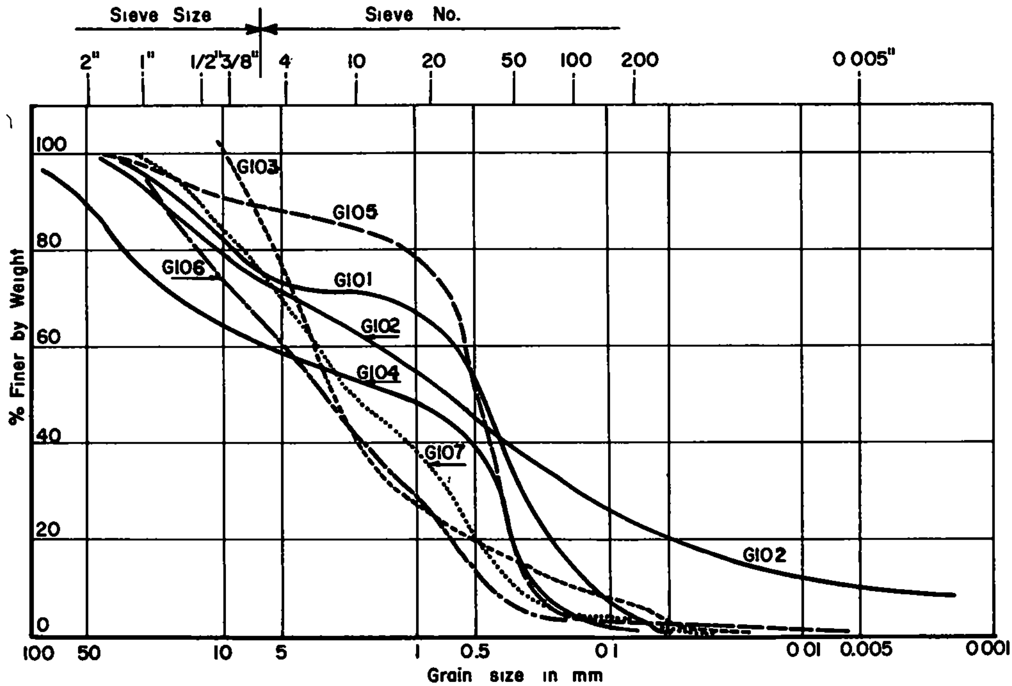

Figure 1. Grain size curve for the natural gravels.

METHODS OF TEST

Mixing

Batches of the lime-fly ash-gravel mixture, in an amount sufficient to make 3 (4 in. dia. x 4.6 in. high) specimens were prepared in the following manner. All mixing of materials was done by hand with the air dried materials (lime, fly ash, gravel) being blended first into a uniform mixture. The water was then incorporated into the mix until it appeared that the water had been evenly distributed. Due to the lack of appreciable amounts of silt and clay, it was a relatively simple matter to get a uniform mix. The amount of water added to each mixture was the one required to produce the maximum dry density under a standard Proctor compactive effort. The optimum moisture content, maximum dry density, and percentages of lime and fly ash in each mixture are given in Table 3.

Molding

Standard Proctor size samples were molded immediately after mixing in accordance generally, with ASTM Designation D-698T (Method A). Variations to this procedure were as follows:

1. Gravel sizes up to ¾ in. or 1 in., depending on the gradation of the gravel, were used in the sample.
2. Samples for the evaluation of the natural gravels were molded using different compactive efforts. One set of samples was made using standard AASHO compaction and one set was made using a compaction intermediate between standard and modified. This intermediate compaction consisted of 3 layers; 25 blows per layer of the 10 lb rammer dropped 18 inches.

Twenty-four samples were made using each natural gravel; 12 samples by standard compaction and 12 by intermediate compaction.

TABLE 2

PROPERTIES OF MANUFACTURED GRAVELS

Sample Desig.	Sample Manufacturing	Sieve Anal (% passing) 1 In.	No. 4	No. 10	No 200	0 005 In.	Uniform. Coeff, D_{60}/D_{10}	Atterberg Limits L L	P I	USBPR Class.
N. J.	New Jersey gravel	77	59	53	1.4	–	25 4	0	N. P	A-1-b
N J 0	New Jersey sieved on No. 200	76.7	58 8	52.7	–	–	23	0	N. P.	A-1-b
N. J 5	New Jersey + 5.5% overbd	78	61 5	56	6 5	1 6	25	0	N. P.	A-1-b
N. J 10	New Jersey + 11% overbd	79.4	63.7	58 5	11 7	3 3	58	0	N P.	A-1-b
N J 15	New Jersey + 16.5% overbd	81	66	61	16 9	5	106	0	N P.	A-1-b
N. J 20	New Jersey + 22% overbd	82 3	68.1	63.5	22 1	6 6	142	0	N. P.	A-1-b
N. J 25	New Jersey + 27 5% overbd	83.7	70.2	66	27	8	146	0	N. P.	A-2-4

Note: USBPR Class. = U. S. Bureau of Public Roads Classification.
Overburden (overbd.) = selected overburden material used to add fines to the natural gravel.

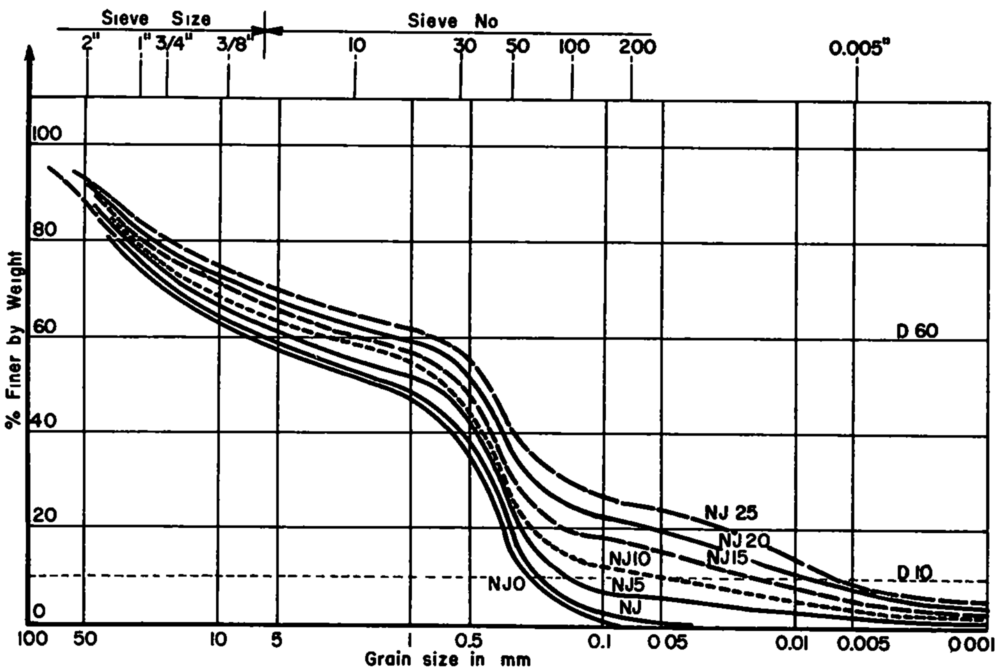

Figure 2. Grain size curve for the manufactured gravels.

Fifteen samples were made for each of the six manufactured gravels. In this case, however, only the standard AASHO compaction was used.

Curing

The following procedure was used for curing test samples:

7 Days Accelerated Cure.—Each specimen after molding was placed in a sealed container. The container was then placed for 7 days in an oven at 130 + 3 F after which period the specimen was removed from its container and submerged for 24 hr in water. The specimen was then tested within 1 hr after removal from water.

28 Days Moist Sand Curing or Beam Box Curing.—After molding, the specimens were placed for 28 days on a 1-in. layer of moist sand, surrounded by sand and covered by another 1-in. layer of moist sand. The sand was moistened daily by approximately ³⁄₈ gal per sq yd. After the 28-day period the specimens were removed, submerged for 24 hr in water and then tested within 1 hr after removal from water.

TABLE 3

EVALUATION OF NATURAL GRAVELS — TEST RESULTS

Sample Desig	Mixture Composition: Moist Cont (%)	Lime (%)	Fly Ash (%)	Dry Density (pcf): 10-Lb Hammer Max	Min	Avg	5 5-Lb Hammer Max	Min	Avg	Comp Strength (psi): 10-Lb Hammer A C	B B	5 5-Lb Hammer A C	B B	Frost Suscp (% wt loss): 10-Lb	5 5-Lb	% Water Absorption: Absorbed Water/Oven Dry Wt (%)	After 12 F -T Cycles
G-101	8	4	10	133	130	133	125	123	124	550	180	460	165	66	52	15	13
G-102	10	4	15	120	115	117	119	113	115	570		350	330	8 0	100	15	16
G-103	6 8	4	10	140	135	136	138	133	136	1,300	820	1,300	830	1 5	3	4	7
G-104	7 7	3	11	138	135 5	137	138	133	135	1,280	710	1,380	680	2	3	4 5	7 5
G-105	8 5	4	15	128	124	126	126	120	122 5	1,125	380	1,000	340	14	17	7	11
G-106	7 5	4	12 5	138	135	136	134	129	132	1,600	810	1,700	1,100	1 4	2 8	8	7
G-107	8 1	4	12	132	129	130 5	131	129	130	1,400	475	1,340	465	7 9	8 3	5 4	7 8

Note: F -T = freezing-thawing cycle A C = 7-day accelerated cure 10-Lb or 5 5-Lb = hammer used for compaction
B B = 28-day moist sand curing (beam box) Percentages of lime and fly ash are by weight

Evaluation

Unconfined Compressive Strength.—The test specimens were tested in accordance with ASTM Designation C-39-56T, using a Universal Hydraulic Testing Machine. At least three cyclinders were used for each compressive strength value given in this report. All specimens were capped before they were broken.

Freezing-and-Thawing Test.—1. Frost Susceptibility—Those specimens that were moist cured for 28 days were subjected to 12 cycles of freezing and thawing as set forth in that porttion of ASTM Designation D-560 pertaining to the weight loss specimen. This test was performed where both the natural gravels and the manufactured gravels were used in the mixture. 2. Durability—Those specimens that were cured using the 7-day accelerated cure were subjected to 12 cycles of freezing and thawing as set forth in that portion of ASTM D-560 pertaining to the weight loss specimen. Only the mixtures containing the manufactured gravels were subjected to this test.

Water Absorption.—1. Test samples that were cured by the 7-day accelerated cure were air dried to constant weight and placed on ¼ in. thick absorbent pads. Free water was made available at the base of the pad. The specimens were allowed to absorb water until they achieved a constant weight. 2. The absorption of water during the freeze-thaw tests after 12 cycles was also observed and recorded.

TABLE 4

EVALUATION OF "MANUFACTURED" GRAVELS — TEST RESULTS
USING ONLY THE 5 5-LB HAMMER FOR COMPACTION

Sample Desig	Mixture Composition: Moist Cont (%)	Lime (%)	F A (%)	Dry Density (pcf): Max	Min	Avg	Compress Strength (psi): A C	B B	After 12 F -T Cy: A C	B B	Durability (% wt loss)	Frost Suscp (% wt loss)	Absorption (%): Absorbed Water/Oven Dry Wt (%)	After 12 F -T Cycles
N J	8 1	4	12	131	129	130	1,340	465	1,130	520	3 8	8 3	5 4	7 8
N J 0	7 6	4	12	129	125 8	127 5	1,000	340	1,000	350	8 0	10	6 1	8 2
N J 5	9	4	12	132 6	130	131 3	1,100	430	875	455	4	2.7	4 5	7
N J 10	9 7	4	12	129	126	128	1,030	320	850	160	4	35	5	10 5
N J 15	10 2	4	12	129	126	126 8	950	285	800	56	4 5	70	5 8	11 6
N J 20	10 9	4	12	127	124 7	125 4	905	225	720	48	4 6	100 After 12 F - T	6 5	12 5
N J 25	11 7	4	12	123 2	121 5	122 5	820	220	740	—[a]	10 5	100 After 12 F - T	10	13 5

Note F-T-C = Freezing-thawing cycle A C = 7-day accelerated cycle
B B = 28-day beam box cure [a] = failed

Number of Tests.—Tables 5 and 6 give the type of test used for evaluation and the number of specimens involved.

TEST RESULTS

Test results pertaining to (a) unconfined compressive strength, (b) frost susceptibility, (c) curability, and (d) water absorption are summarized in Tables 3 and 4.

Table 3 contains the results of the evaluation of the natural gravels and Table 4 contains the results of the evaluation of the manufactured gravels.

Discussion

Evaluation of Natural Gravels.—An analysis of the results of this part of the investigation shows that the following variables or combination of variables affect the performance of lime-fly ash-gravel mixtures: (a) gradation of the gravel (uniformity and percent fine material), (b) hardness of the gravel, and (c) soundness of the gravel.

With the amount of data that were acquired in this study it was not possible to determine an exact relationship between the aforementioned variables and the laboratory performance of the mixtures. However, indications of their effects were rather clear.

As an example, Figure 3 shows that the highest strengths (both cures) were achieved with gravel G-106. G-106 was a well-graded sandy gravel with a low percentage of

TABLE 5

SCHEDULE OF EVALUATION TESTS — LIME-FLY ASH-NATURAL GRAVEL

Test	Curing Time (days)	Samples Tested, Each Mix.	Data Obtained
Unconf. compr. str.	7 28	3 3	Unconf. compr. str.
Frost suscept.	28	3	% Wt. loss, water abs.
Water absorp.	7	3	Water absorbed

TABLE 6

SCHEDULE OF EVALUATION TESTS — LIME-FLY ASH-MANUFACTURED GRAVEL

Test	Curing Time (days)	Samples Tested, Each Mix.	Data Obtained
Unconf. compr. str.	7 28	3 3	Unconf. compr. str.
Frost suscept.	28	3	% Wt. loss, water abs. compr. str. after freeze-thaw
Durability	7	3	% Wt. loss, water abs. compr. str. after freeze-thaw
Water absorp.	7	3	Water absorbed

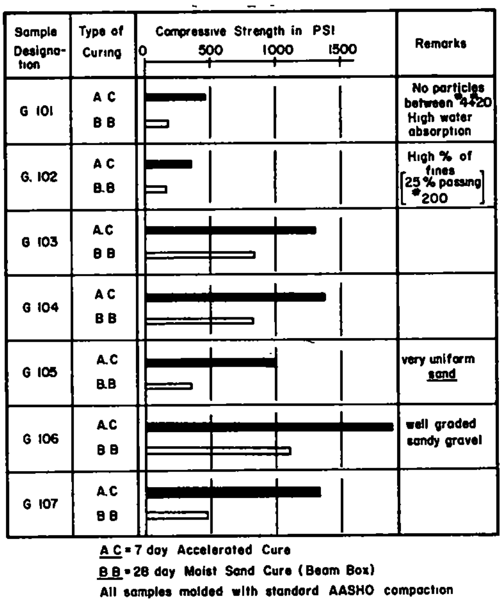

Figure 3. Compressive strength of lime-fly ash-gravel compositions using natural gravels.

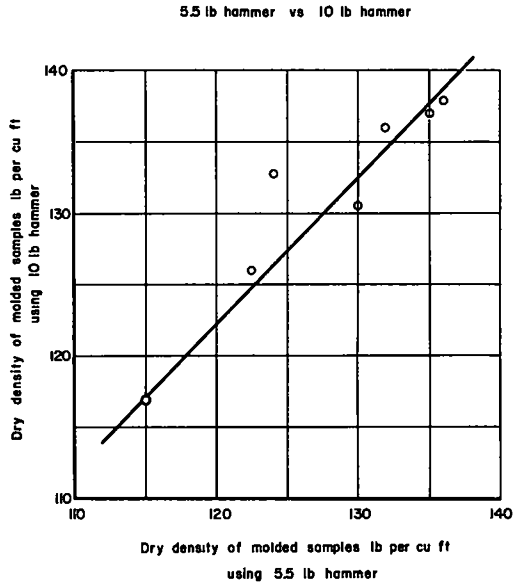

Figure 4. Variation in molded density of test sample using natural gravels.

fines (3.2 percent passing the No. 200 sieve). It also had the lowest percentage of loss during the hardness test. On the other hand, the lowest strengths were recorded for the lime-fly ash-aggregate compositions using gravel G-102. This gravel contained the highest percentage of fines (about 23 percent) and had the highest losses in the hardness and soundness tests.

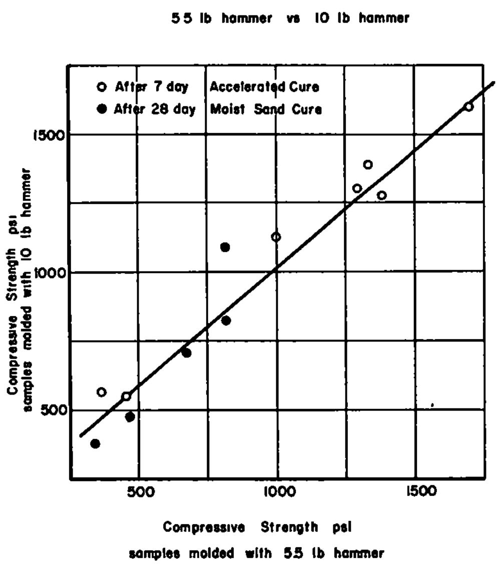

Figure 5. Variation in compressive strength of test sample using natural gravels.

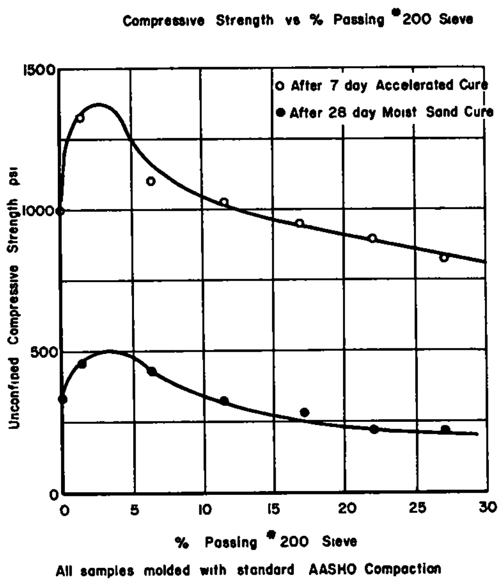

Figure 6. Variation in compressive strength of test sample using manufactured gravels.

The other evaluation tests showed results that were consistent with those of the unconfined compression test. Referring to Table 3, it can be seen that mixtures that gave high compressive strengths also had low weight losses during frost-susceptibility tests, and low water absorption. The water absorption test showed considerable promise as a "yardstick" for measuring laboratory performance. In every case where the percent water absorbed remained below the optimum or molded moisture the compressive strengths were high and the losses during frost-susceptibility tests were low. In two of the three cases (G-101, G-102, G-106) where the percent water absorbed exceeded the optimum or molded moisture content, the compressive strengths were substantially lower and the frost-susceptibility losses were high.

Figure 4 shows the relationship between the densities obtained by compacting with a 10-lb hammer—18-in. drop, and those obtained by compacting with a 5.5-lb hammer—12-in. drop. The greater compactive effort gave densities that ranged from 0.5 to 9 pcf higher than those with the 5.5-lb hammer. The effects of heavier compaction on compressive strength were found to be small. This was particularly true of the mixtures.

Figure 5 shows the close equivalence in compressive strengths.

Evaluation of Effect of Fines (Percent Passing No. 200 Sieve) on Lime-Fly Ash-Gravel Mixtures. —As the percentage of fines was varied in the "manufactured" gravels there was a substantial variation in the compressive strengths. This effect is shown in Figure 6. For this particular gravel there appears to be an optimum percentage of fines with regard to compressive strength. This optimum is between 3 and 5 percent of fines. As the percentage of fines in the gravel was increased beyond this optimum, the compressive strength decreased. This trend was shown in samples that were cured by the 7-day accelerated cure and by those that were cured by the 28-day moist sand cure. The unconfined compressive strengths of the samples that were cured by the moist sand cure averaged about 30 percent of the strength of the accelerated cure samples.

In Figure 7, the dry density of samples compacted with the 5.5-lb hammer is compared with the percent of fines in the gravel. This curve is similar in appearance to the curve of Figure 6. The maximum dry density was achieved with the gravel that contained about 4 percent of fines and a continuous decrease in density was obtained with an increase in fines beyond this amount.

The concept of an optimum percentage of fines appears to be substantiated by the results of the frost susceptibility tests as shown in Figure 8. The weight loss of the wire-brushed samples (shown as frost susceptibility—percent weight loss) during the freeze-thaw test is shown in this figure as a function of the percentage of fines. The

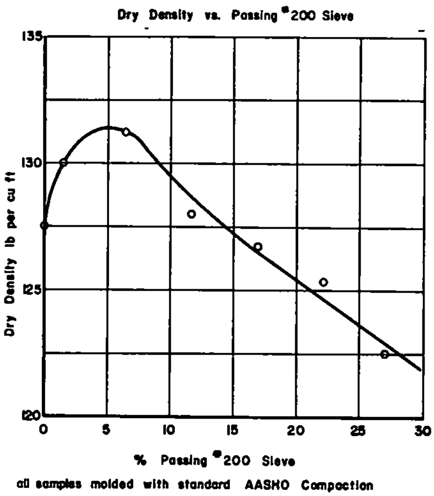

Figure 7. Variation in molded density of test sample using manufactured gravels.

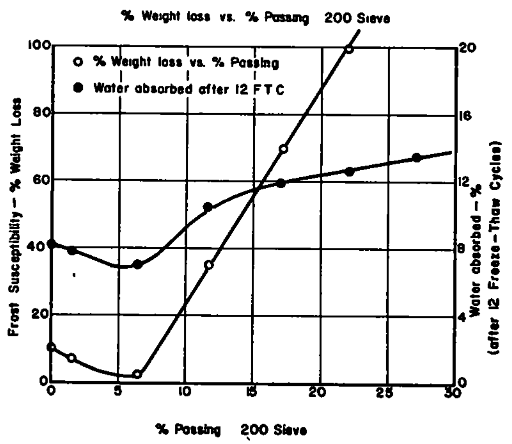

Figure 8. Frost susceptibility—percent weight loss using manufactured gravels.

smallest loss occured with the gravel that contained about 5 percent of fines and the amount of loss increased with an increase in fines content. The water absorbed vs percent passing the No. 200 sieve is also shown in Figure 8. The trend of this curve is similar to the weight loss curve. Again it can be pointed out that the water absorption test gives the same information that is obtained in the compressive strength and durability tests. Further study of the use of this test in evaluating lime-fly ash-aggregate mixtures is warranted.

CONCLUSIONS

This investigation has shown that variations in physical properties of gravel particles and gravel aggregates do affect the laboratory performance of lime-fly ash-gravel compositions. Certain generalizations can be made regarding these properties. Although these generalizations should be verified by additional data, the present study has indicated the following:

1. The compressive strengths of samples made with a 5.5-lb hammer were essentially the same as those made with a 10-lb hammer. This was true even though the densities with the lighter compaction were somewhat lower (2 to 4 pcf for the better gravels).
2. There are indications of a correlation between the performance of a gravel in a lime-fly ash composition and the properties of the gravel itself. The best results from the standpoint of compressive strength and durability were achieved with those gravels that had: (a) a low percentage of fines; (b) a relatively low weight loss in hardness and soundness tests; and (c) a good gradation of particle sizes.
3. Mixtures that had high compressive strengths in samples that were cured by the 28-day moist sand cure also showed low losses in the frost susceptibility test and a low water absorption.
4. This study has shown that, for the particular gravel that was evaluated, optimum results were obtained when the percentage of fines was approximately 4 percent. Optimum results were indicated by relatively high compressive strengths and densities, low losses in durability tests, and a low water absorption.
5. Most of the compressive strength values show a proportional increase with an increase in the dry density of the compacted sample.
6. The use of a water absorption test for evaluating lime-fly ash-aggregate compositions shows promise. The data acquired by this test show the same trend as the data from the compressive strength and durability tests. The simplicity of the water absorption test would also make it desirable.