CONCRETE WEAR STUDY

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SYNOPSIS

This report primarily investigates the wear characteristics of concrete using various cement contents and three different sources of aggregates. Compressive strength and dynamic modulus of elasticity data was also obtained to assist in the evaluation of these various mixes.

The testing program covered specimens representing various ages, cement contents and aggregates. The aggregates used were from sources readily available and suitable for construction purposes in this state.

Results of this study were:

1) The wear resistance of concrete mixes was not always predictable from abrasion loss results of the aggregate used in the mix.
2) The wear resistance of concrete mixes was usually improved by the addition of cement up to six sacks per cubic yard. After this another sack per cubic yard did not necessarily increase the wear resistance.
3) The use of admixtures in some cases reduced the wear resistance of concrete mixes.
4) Compressive strength was not an absolute indication of wear resistance in that some mixes with high compressive strength exhibited lower wear resistance than mixes with lower compressive strength.
5) Lightweight concrete generally exhibited less wear resistance than did concrete containing normal weight aggregate.

CONCRETE WEAR STUDY

INTRODUCTION

This study evaluates the wear characteristics of concrete with varying cement contents and different sources of coarse aggregates also the affects of concrete admixtures on the resistance to wear.

The wear tests, using a Concrete Abrasion Machine, were performed first to conform to the requirements of ASTM C 418-58T and then to conform to the requirements of ASTM C 418-64. Compressive strength and dynamic modulus of elasticity were determined for each mix tested.

SCOPE

Two normal weight coarse aggregates and one lightweight coarse aggregate were selected for study. The lightweight coarse aggregate was used in concrete mixes containing 5.0, 6.0 and 7.0 sacks of cement per cubic yard with admixtures. The normal weight aggregates were used in concrete mixes containing 4.0, 5.0, 6.0 and 7.0 sacks of cement per cubic yard, with and without admixtures. Wear tests, compressive strength tests and dynamic modulus of elasticity determinations were made on each mix at the 28 day, 6 month and 12 month periods.

The study was conducted in these five steps:

(1) Determination of aggregate properties
(2) Molding and curing of specimens
(3) Compression test of cylinder specimens
(4) Dynamic modulus of elasticity determinations of beam specimens
(5) Wear determination of beam specimens

Soon after the work was started and the first wear test results were obtained, it became obvious that the determination of the area of surface abraded as required by the first test procedure was very difficult and the values used were not too accurate. It was decided to eliminate the surface area value from the test and concentrate on comparison by the volume in cubic centimeters of abraded material. This resulted in more reliable data.

It should be noted that in 1964, ASTM revised the test procedure to require a metal shield to be placed on top of the specimen with a 1.13 in. diameter hole through the metal. The nozzle of the gun is then to be positioned directly over this hole and the concrete is to be abraded through this opening to determine the surface abraded. However, the position of the nozzle in respect to the opening in the metal is critical and has to be accurately controlled.

METHODOLOGY

Materials

The cement used in all mixes was Type I Portland produced in Baton Rouge, Louisiana.

The aggregates used are described briefly as follows:

Aggregate CA-1 - A natural, uncrushed, predominantly silicious coarse aggregate from the Amite River near Baton Rouge, Louisiana.

Aggregate CA-2 - A natural, uncrushed, predominantly silicious coarse aggregate from the Pearl River near Pearl River, Louisiana.

Aggregate CA-3 - An expanded clay lightweight coarse aggregate manufactured in Louisiana.

Aggregate CA-4 - A coarse aggregate from the Amite River with the gradation changed to compare with the Pearl River aggregate.

Aggregates FA-1a and FA-1b - Natural, uncrushed, predominantly silicious fine aggregates from the Amite River near Baton Rouge, Louisiana.

The admixtures used in this study consisted of a water reducing, set retarding agent and an air entraining agent. The water reducing, set retarding admixture and the air entraining agent were used at the rates shown in Tables 2 and 7.

Test Procedures for Aggregates

The aggregates were prepared and tested in accordance with the methods listed below:

AASHO T-104-57 - Method of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate, (using Magnesium Sulfate).

AASHO T-96-60 - Method of Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine.

AASHO T-19-56 - Method of Test for Unit Weight of Aggregate.

AASHO T-84-60 - Method of Test for Specific Gravity and Absorption of Fine Aggregates.

AASHO T-85-60 - Method of Test for Specific Gravity and Absorption of Coarse Aggregates.

Test Results for Aggregates

The gradations, unit weights, specific gravities, soundness losses and abrasion losses are shown in Table 1 of Appendix A and Table 6 of Appendix B.

Concrete

Concrete mixes were made with cement contents of 4.0, 5.0, 6.0 and 7.0 sacks per cubic yard, with and without admixtures, for each of the normal weight coarse aggregates under study. Cement contents of 5.0, 6.0 and 7.0 sacks per cubic yard with admixture were used for the lightweight coarse aggregate.

The mix designs used and the proportions of the fresh concrete are given in Table 2 of Appendix A and Table 7 of Appendix B. The concrete was mixed in a 3.5 cu. ft. revolving drum mixer. The aggregates and approximately two-thirds of the mixing water, including the admixtures when required, were placed in the mixer and mixed for one minute. The cement and remaining water were then added and the mixing continued for four additional minutes. The concrete was then dumped into a large metal pan and the necessary tests and test specimens were made.

Test Procedures for Concrete

The test procedures used in determining the properties of the fresh concrete, molding the test specimens and the testing of these specimens were:

AASHO T152-57 - Method of Test for Air Content of Freshly Mixed Concrete by the Pressure Method

AASHO T119-60 - Method of Test for Slump of Portland Cement Concrete

AASHO T22-60 - Method of Test for Compressive Strength of Molded Concrete Cylinders

AASHO T126-60 - Method of Test for Making and Curing Concrete Compression and Flexural Test Specimens in the Laboratory

ASTM C215-60 - Method of Test for Fundamental Transverse, Longitudinal and Torsional Frequencies of Concrete Specimens

ASTM C418-58 - Method of Test for Abrasion Resistance of Concrete

ASTM C418-64 - Method of Test for Abrasion Resistance of Concrete

Molding and Curing Specimens

The molding of specimens consisted of preparing nine 6 in. by 12 in. concrete cylinders and nine 3 in. by 4 in. by 16 in. beams for each concrete mix. Air temperatures and mix temperatures were recorded, and actual cement factors were calculated. The beams were used for dynamic modulus of elasticity and for wear evaluation.

All specimens were cured for seven days at 100% humidity and 73°F. After seven days the specimens were removed from the damp room, stored outside the laboratory and exposed to normal atmospheric conditions until the time of each test. A record was maintained of the ambient temperatures for the period that the specimens were under test. This information is shown in Table 3 of Appendix A and Table 8 of Appendix B.

Testing of Specimens

After 28 days three cylinders were tested for compressive strength, and wear tests were performed on three beams. Prior to performing the wear tests, dynamic modulus readings were taken on the beams. This same procedure was followed for the remaining specimens after 6 and 12 months. Due to vandalism in the storage area, all 6 and 12 month compressive strength tests were performed on 3 in. by 4 in. by 8 in. specimens by cutting one of the wear test specimens in half.

The first test procedure for determining wear was ASTM C418-58T. The shot-blast-apparatus consisted of an infector-type gun having a high-velocity air jet fed by a suitable controlled rate of flow for the abrasive material. The nozzle consisted of cold-rolled bar stock 1.5 in. long drilled to 0.250 ± 0.001 in. through the center. The walls of the nozzle had a 45° bevel on the inside at the upper end. A compressed air supply of approximately 100 psi was available with a pressure control device.

The abrasive was a natural silica sand, graded to pass a No. 20 (840 micron) sieve and retained on a No. 30 (590-micron) sieve, and was from Ottawa, Illinois.

The specimens (3 by 4 by 16 in. concrete beams) were immersed in water for 24 hours then surface-dried with a damp cloth to obtain a saturated, surface-dry condition at the time of the test.

The air pressure was adjusted to 60 ± 1 psi and the abrasive was collected for a period of one minute. The rate of flow was then adjusted, if necessary, to produce 600 ± 25 grams per minute of the abrasive material.

The weighed specimen was placed into position with the surface to be tested normal to the nozzle axis and at a distance of 3 ± 0.1 in. from the end.

The results of the dynamic modulus test, the compressive strength test and the wear test are shown in Tables 4 and 5 of Appendix A and Tables 9 and 10 of Appendix B.

After completion of the first part of the study, these questions were raised: (1) Why did the concrete mixes containing the harder aggregate from the Baton Rouge area exhibit higher abrasion loss than the concrete mixes containing the softer aggregate from the Pearl River area? (2) Does the use of admixtures affect the wear resistance of concrete to any great extent? (3) Would mortar screened from a concrete mix show similar wear resistance to the original concrete mix from which the mortar was obtained?

In an effort to obtain the answers to these questions, the mixes containing aggregates CA-1, CA-2, and CA-3 made in the first study were duplicated and two other mixes were used. Mortar specimens were made using mortar screened from the concrete mixtures containing the Baton Rouge area aggregate, and a concrete mix was made using aggregate CA-4. Aggregate CA-4 was used in an effort to produce compressive strength as nearly equal as possible to aggregate CA-2.

The second method of performing the abrasion tests on the concrete specimens, using the revised ASTM C418-64 procedure, permitted a more accurate determination of abrasion loss. The materials, test procedures for aggregates, and the molding and curing of specimens were identical to the first test procedure.

DISCUSSION OF RESULTS

There were three principal relationships under study in this project: (1) the affect of cement content on resistance to wear, (2) the affect of different coarse aggregates on resistance to wear and (3) the affect of concrete admixtures on resistance to wear. In addition, information was obtained on compressive strength and dynamic modulus of elasticity to assist in evaluating each mix.

Figures 1, 2 and 3 graphically illustrate the affects of cement content on wear characteristics. It was expected that the higher the cement content and the older the concrete, the less would be the wear. This was true except for the mixes containing seven sacks of cement per cubic yard. In these mixes the lowest wear was obtained at six months, with an increase in wear exhibited at twelve months. This was the case for the first series of tests. When Coarse Aggregates CA-1 and CA-2 were used in conjunction with seven sacks of cement per cubic yard and admixtures, the wear loss was greater at twelve months than comparative mixes containing six sacks of cement per cubic yard. These results perhaps indicate that after a certain amount of cement is used in conjunction with admixtures, any increase in the cement content will actually reduce the ability of the concrete to withstand wear.

Figures 4, 5, 6 and 7 show a graphical comparison of the three sources of aggregates used in the first series of tests at each cement content, with and without admixtures.

Coarse Aggregate CA-1, which gave the lowest results on the Los Angeles abrasion test, produced a higher wear loss when used in concrete than did Coarse Aggregate CA-2 for all mixes except for a cement content of six sacks per cubic yard with admixtures and seven sacks per cubic yard without admixtures. In these two cases, the wear on concrete with Coarse Aggregate CA-2 was slightly higher than with Coarse Aggregate CA-1. In all cases, the concrete made using Coarse Aggregate CA-3 (lightweight) had a higher loss on wear than did the concrete made from Coarse Aggregates CA-1 and CA-2.

The influence of admixtures on wear characteristics was most pronounced with Coarse Aggregate CA-2. With cement contents of four, five and six sacks per cubic yard, the wear resistance was increased with the use of admixtures. The seven sack mix with admixtures had better results at 28 days than the mix without admixtures, but at 6 and 12 months the results were almost identical. The comparison of mixes made with Coarse Aggregate CA-1 was not as definite. The four sack mix gave the best results without admixtures; the five sack mix did not exhibit any definite trend; the six sack mix gave best results without admixtures; and the seven sack mix gave best results with admixtures. The lightweight mixes were all made with admixtures; therefore, no comparison could be made.

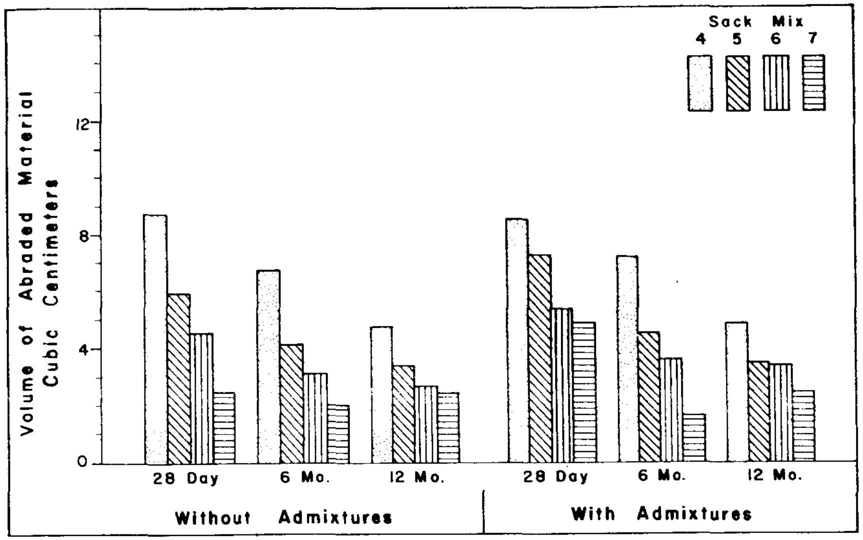

Figure 1 - Coarse Aggregate CA - 2

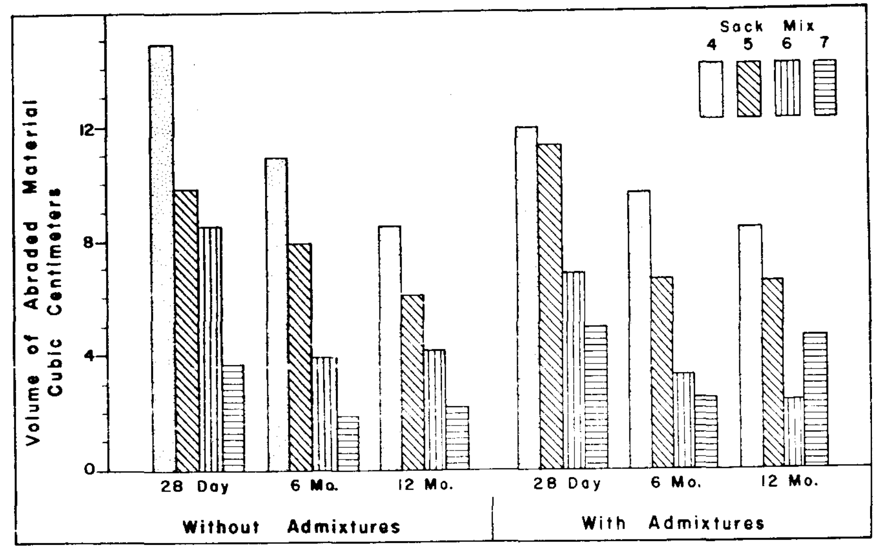

Figure 2 - Coarse Aggregate CA - 1

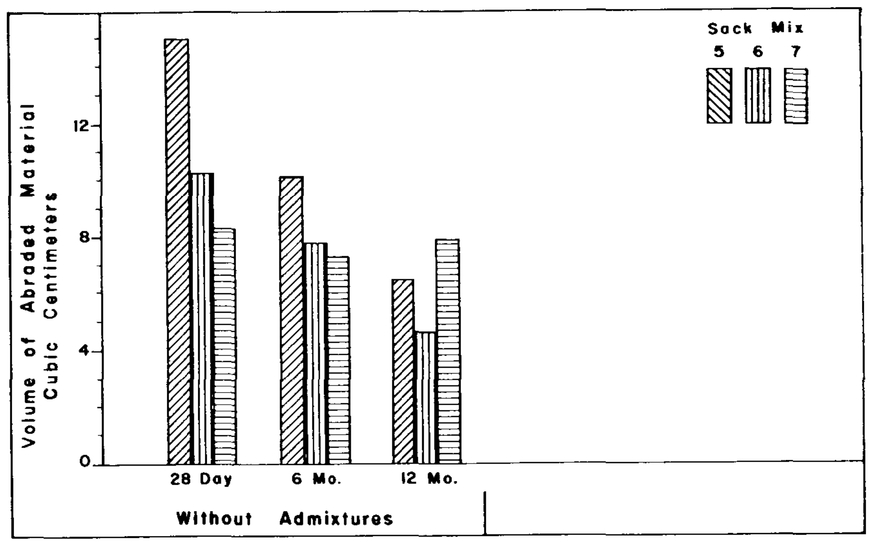

Figure 3 - Coarse Aggregate CA - 3

Effect of Cement Content on Wear Resistance

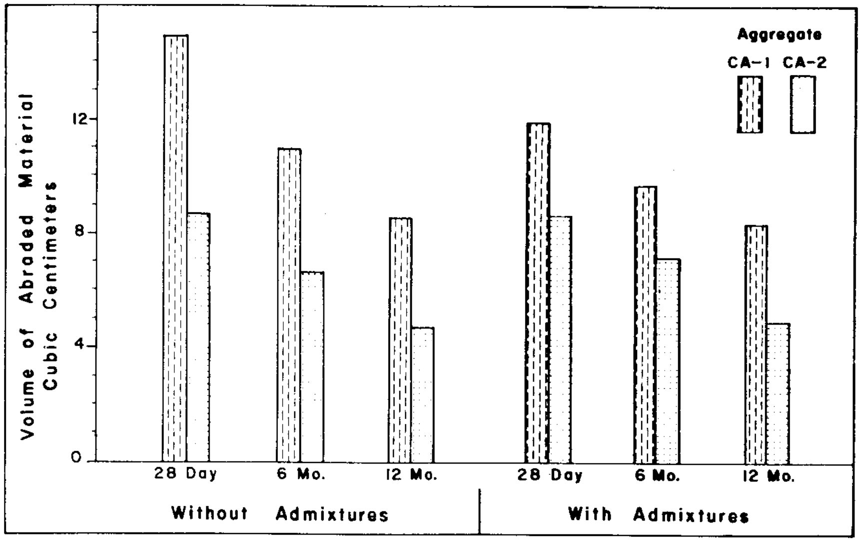

Figure 4 - 4 Sack Mix

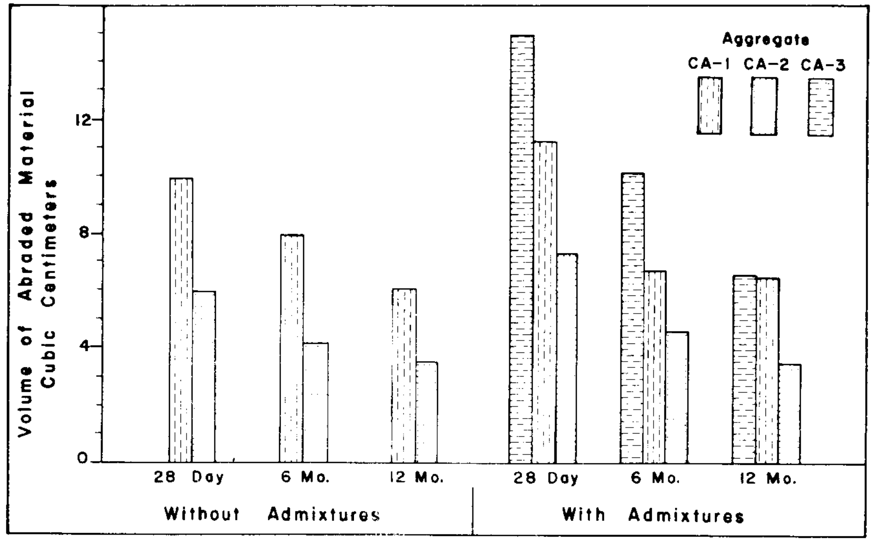

Figure 5 - 5 Sack Mix

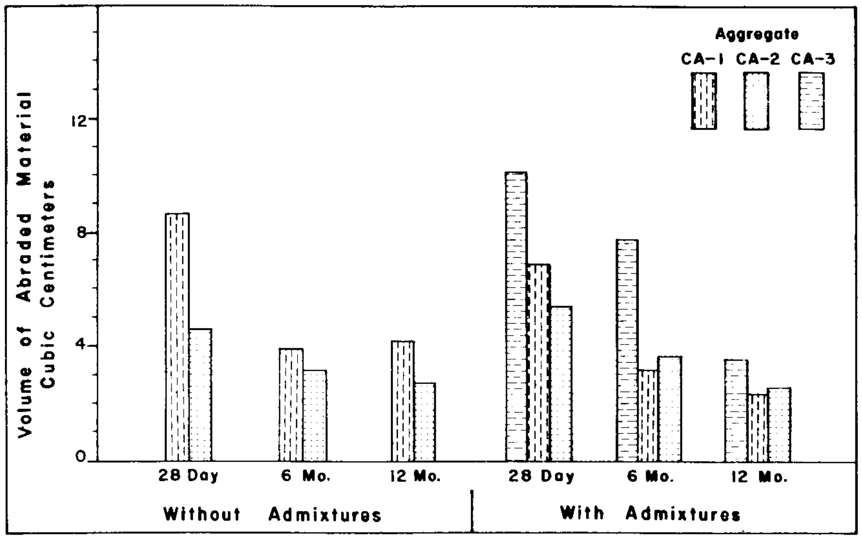

Figure 6 - 6 Sack Mix

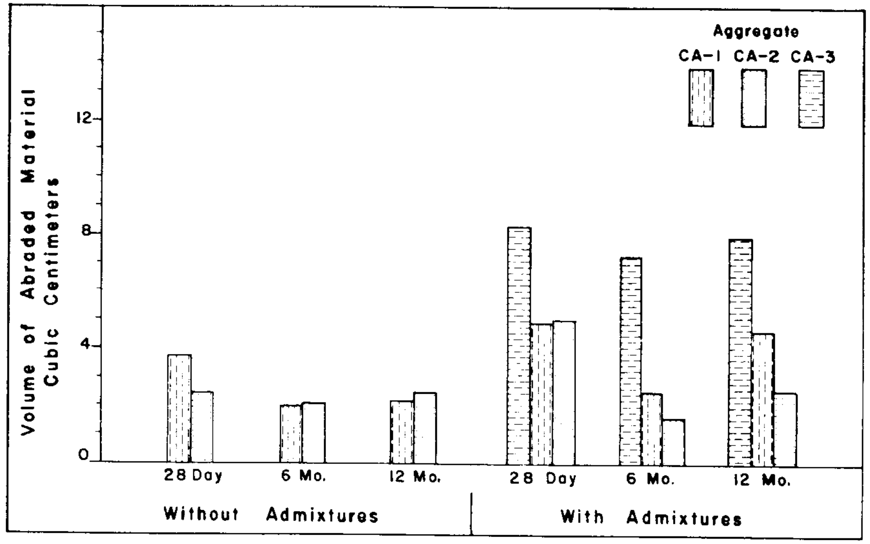

Figure 7 - 7 Sack Mix

Effect of Aggregate Source on Wear Resistance

Some of the results obtained from this first part of the study did not follow what would normally be expected. For instance: (1) the wear results obtained at 12 months for the seven sack mixes indicated more wear loss than was found at an age of 6 months; and (2) the normal-weight coarse aggregate which had the lowest abrasion loss, the highest specific gravity and unit weight and the lowest soundness loss gave higher on wear than the normal weight aggregate which had higher abrasion loss, lower specific gravity and unit weight and a higher loss on soundness. The only explanation for a higher loss on wear occurring at 12 months than at 6 months is that, due to the small volume of material being abraded on these specimens, a small error in the test would affect the result considerably. The reason for the softer aggregate's producing concrete with more wear resistance than the harder aggregate could possibly be due to the finer gradation of the softer aggregate. This produced compressive strengths from 20% to 60% higher at 28 days and from 20% to 40% higher at one year than concrete made from the harder aggregate.

Figures 8 - 12 graphically illustrate the results of abrasion loss obtained from all concrete and mortar mixes made in the second part of the study. The results compliment the findings of the first study in that the wear resistance of the concrete made using the aggregate from the Pearl River and containing no admixtures was higher in most cases than the wear resistance on the concrete made using the Amite River aggregate containing no admixtures. The use of admixtures appeared to increase the wear resistance of the Amite River aggregate concrete in the four and five sack mixes and to decrease the wear resistance slightly in the six and seven sack mixes. Admixtures used in the concrete containing Pearl River aggregate appeared to be detrimental to the wear resistance in almost every case.

The wear resistance of the lightweight concrete was lower in every case than the companion normal weight concrete.

The wear resistance of the mortar specimens was extremely inconsistent and no definite trend could be established. In some cases the mortar mixes showed better wear resistance, while in others the wear resistance was worse.

CONCLUSIONS

(1) The wear resistance of concrete mixes was not always predictable from abrasion loss results of the aggregate used in the mix.
(2) The wear resistance of concrete mixes was usually improved by the addition of cement up to six sacks per cubic yard. After this another sack per cubic yard increase did not necessarily increase the wear resistance.
(3) The use of admixtures in some cases reduced the wear resistance of concrete mixes.
(4) Compressive strength was not an absolute indication of wear resistance in that some mixes with high compressive strength exhibited lower wear resistance than mixes with lower compressive strength.
(5) Lightweight concrete generally exhibited less wear resistance then did concrete containing normal weight aggregate.

RECOMMENDATIONS

A correlation between wear loss in the laboratory and rate of wear on roadway surfaces is badly needed. With this information available, laboratory investigations could be made prior to the use of aggregates with questionable or unknown service histories to determine if limitations should be placed on the use of the aggregate.

This type study would have to be of a major magnitude in order to be worthwhile and to supply the needed information. It would probably be best suited to a NCHRP project.

APPENDIX A
PHASE I

TABLE 1

PHYSICAL PROPERTIES OF AGGREGATES

GRADATION

Coarse Aggregate				Fine Aggregate		
U. S. Sieve	CA-1	CA-2	CA-3	U.S. Sieve	FA-1A	FA-1B
	Per Cent Passing				Per Cent Passing	
1 1/2 inch	100	100		3/8 inch	100	100
1 inch		99		No. 4	98	98
3/4 inch	75	92	100	No. 8	93	86
1/2 inch	30	52	93	No. 16	84	70
3/8 inch		26	70	No. 30	58	52
No. 4	0	3	6	No. 50	10	17
No. 8			2	No. 100	1	1

UNIT WEIGHT, SPECIFIC GRAVITY, SOUNDNESS AND ABRASION LOSS

	CA-1	CA-2	CA-3		FA-1A	FA-1B
Unit wt. lb/cu. ft. Rodded	98.4	97.5	43.0		110.0	112.0
Unit wt. lbs/cu Loose	90.4	89.5	39.0		102.0	104.0
Bulk SSD Specific Gravity	2.54	2.52			2.62	2.62
Soundness Loss Magnesium Sulf. %	3.6	6.95	6.98			
Los Angeles Abrasion Loss Grade B %	18.2	18.8	29.5			

TABLE 3

AVERAGE MONTHLY TEMPERATURES FROM DAILY RECORDING

Month	Year	High	Low	Average High	Average Low
First Phase (Aggregates CA-1 and CA-3) began 8-14-63 and ended 9-9-64					
September	1963	94°F	54°F	87°F	66°F
October	1963	94°F	46°F	90°F	61°F
November	1963	84°F	38°F	76°F	50°F
December	1963	71°F	26°F	53°F	37°F
January	1964	80°F	21°F	61°F	40°F
February	1964	75°F	25°F	64°F	41°F
March	1964	84°F	38°F	75°F	50°F
April	1964	94°F	44°F	82°F	61°F
May	1964	105°F	52°F	92°F	66°F
June	1964	104°F	62°F	97°F	68°F
July	1964	105°F	68°F	98°F	71°F
August	1964	104°F	69°F	98°F	72°F
September	1964	101°F	58°F	89°F	69°F
Second Phase (Aggregate CA-2) began 4-6-64 and ended 4-20-65					
April	1964	94°F	44°F	82°F	61°F
May	1964	105°F	52°F	92°F	66°F
June	1964	104°F	62°F	97°F	68°F
July	1964	105°F	68°F	98°F	71°F
August	1964	104°F	69°F	98°F	72°F
September	1964	101°F	58°F	89°F	69°F
October	1964	90°F	43°F	80°F	56°F
November	1964	84°F	32°F	73°F	56°F
December	1964	78°F	29°F	64°F	50°F
January	1965	80°F	24°F	66°F	45°F
February	1965	79°F	28°F	62°R	44°F
March	1965	84°F	29°F	66°F	48°F

Note: All temperatures were taken in the open, not in the shade.

TABLE 4

AVERAGE COMPRESSIVE STRENGTH AND DYNAMIC MODULUS RESULTS

Mix Identification	Age at Test	Compressive Strength	Dynamic Modulus
	28 days	2850	4,944,584
	6 months	3175	5,462,455
R-4	12 months	3457	5,514,427
	28 days	3186	5,312,208
	6 months	3816	5,642,636
A-4	12 months	4163	5,629,398
	28 days	3340	5,605,033
	6 months	4317	5,826,865
R-5	12 months	4358	6,084,847
	28 days	3580	5,617,306
	6 months	4458	6,032,369
A-5	12 months	4858	5,852,138
	28 days	4399	6,188,729
	6 months	5124	6,273,399
R-6	12 months	5553	6,346,823
	28 days	4770	5,929,452
	6 months	5548	6,191,223
A-6	12 months	5335	6,110,582
	28 days	5294	6,179,131
	6 months	6478	6,752,990
R-7	12 months	6442	6,628,436
	28 days	5441	5,834,193
	6 months	6101	6,291,902
A-7	12 months	6182	6,119,001
	28 days	4157	2,669,515
	6 months	4699	2,921,661
Y-1	12 months	4480	2,841,105

TABLE 4 (Cont.)

AVERAGE COMPRESSIVE STRENGTH AND DYNAMIC MODULUS RESULTS

Mix Identification	Age at Test	Compressive Strength	Dynamic Modulus
	28 days	5064	2,663,949
	6 months	5536	3,170,864
Y-2	12 months	5977	3,066,667
	28 days	5606	2,788,500
	6 months	6111	3,109,719
Y-3	12 months	6495	3,042,467
	28 days	3663	5,245,468
	6 months	4228	5,842,202
X-1	12 months	4525	5,829,897
	28 days	5400	5,472,423
	6 months	6018	5,881,760
X-2	12 months	6402	5,786,099
	28 days	6443	6,188,561
	6 months	6790	6,525,323
X-3	12 months	6896	6,607,339
	28 days	7591	6,449,591
	6 months	7831	6,652,602
X-4	12 months	8651	6,702,310
	28 days	3952	4,768,698
	6 months	4938	5,433,828
X-5	12 months	4752	5,346,661
	28 days	5088	5,180,526
	6 months	5971	5,551,347
X-6	12 months	6354	5,631,457
	28 days	5865	5,775,843
	6 months	6784	5,725,786
X-7	12 months	7054	5,707,472
	28 days	6035	5,528,468
	6 months	7196	5,853,903
X-8	12 months	7431	6,208,303

TABLE 5
AVERAGE WEAR TEST EVALUATION RESULTS

Concrete Mix Description	Age at Test	Wt. before test, W_1, gr.	Wt. after test, W_2, gr.	Wt. of Abraded Material, W, gr.	Bulk Specific Gravity(SSD)	Volume of Abraded Mat'l(cu. cm.)
R-4	28 days	7419.7	7384.7	35.0	2.346	14.92
(4 Bag Reference,	6 months	7456.7	7431.0	25.7	2.345	10.96
CA-1, FA-1a)	12 months	7452.7	7432.7	20.0	2.353	8.50
A-4	28 days	7322.7	7295.4	27.3	2.285	11.95
(4 Bag Admixture,	6 months	7326.3	7304.3	22.0	2.287	9.62
CA-1, FA-1a)	12 months	7326.3	7307.3	19.0	2.284	8.32
R-5	28 days	7572.3	7549.0	23.3	2.357	9.89
(5 Bag Reference,	6 months	7488.3	7469.6	18.7	2.357	7.93
CA-1, FA-1a)	12 months	7502.3	7488.3	14.0	2.325	6.02
A-5	28 days	7344.3	7319.3	25.0	2.275	11.16
(5 Bag Admixture,	6 months	7316.0	7301.0	15.0	2.280	6.58
CA-1, FA-1a)	12 months	7813.3	7303.6	14.7	2.292	6.41
R-6	28 day	7572.7	7552.7	20.0	2.363	8.59
(6 Bag Reference,	6 months	7531.3	7522.0	9.3	2.356	3.95
CA-1, FA-1a)	12 months	7560.3	7550.6	9.7	2.344	4.14
A-6	28 days	7373.3	7357.6	15.7	2.313	6.79
(6 Bag Admixture,	6 months	7314.0	7306.7	7.3	2.301	3.19
CA-1, FA-1a)	12 months	7327.0	7321.7	5.3	2.300	2.32
R-7	28 days	7540.0	7531.0	9.0	2.368	3.80
(7 Bag Reference,	6 months	7552.0	7547.3	4.7	2.362	1.97
CA-1, FA-1a)	12 months	7513.3	7508.3	5.0	2.357	2.12

TABLE 5 (Cont.)
AVERAGE WEAR TEST EVALUATION RESULTS

Concrete Mix Description	Age at Test	Wt. before test, W_1, gr.	Wt. after test, W_2, gr.	Wt. of Abraded Material, W, gr.	Bulk Specific Gravity(SSD)	Volume of Abraded Mat'l(cu. cm.)
A-7	28 days	7385.7	7474.4	11.3	2.307	4.92
(7 Bag Admixture,	6 months	7355.3	7349.6	5.7	2.296	2.47
CA-1, FA-1a)	12 months	7251.3	7240.6	10.7	2.313	4.62
Y-1	28 days	5421.3	5396.0	25.3	1.690	14.98
(5 Bag Admixture,	6 months	5435.3	5418.3	17.0	1.686	10.08
LW Coarse, FA-1a)	12 months	5299.7	5289.0	10.7	1.662	6.42
Y-2	28 days	5467.0	5449.7	17.3	1.713	10.12
(6 Bag Admixture,	6 months	5499.3	5486.0	13.3	1.709	7.80
LW Coarse, FA-1a)	12 months	5410.7	5403.0	7.7	1.691	4.54
Y-3	28 days	5467.0	5449.7	17.3	1.713	10.12
(7 Bag Admixture,	6 months	5499.3	5486.0	13.3	1.709	7.80
LW Coarse, FA-1a)	12 months	5410.7	5403.0	7.7	1.691	4.54
Y-3	28 days	5534.7	5520.4	14.3	1.730	8.29
(7 Bag Admixture,	6 months	5511.7	5499.4	12.3	1.708	7.23
LW Coarse, FA-1a)	12 months	5453.0	5439.3	13.7	1.716	7.96
X-1	28 days	7352.7	7332.7	20.0	2.332	8.58
(4 Bag Reference,	6 months	7483.3	7468.3	15.0	2.321	6.76
CA-2, FA-1b)	12 months	7439.7	7428.7	11.0	2.323	4.74
X-2	28 days	7266.7	7252.7	14.0	2.340	5.98
(5 Bag Reference,	6 months	7287.3	7277.6	9.7	2.338	4.15
CA-2, FA-1b	12 months	7118.3	7110.3	8.0	2.324	3.44

TABLE 5 (Cont.)
AVERAGE WEAR TEST EVALUATION RESULTS

Concrete Mix Description	Age at Test	Wt. before test, W_1, gr.	Wt. after test, W_2, gr.	Wt. of Abraded Material, W, gr.	Bulk Specific Gravity(SSD)	Volume at Abraded Mat'l(cu. cm.)
X-3	28 days	7507.0	7446.3	10.7	2.350	4.55
(6 Bag Reference,	6 months	7534.3	7527.0	7.3	2.344	3.11
CA-2, FA-1b)	12 months	7518.7	7512.4	6.3	2.334	2.70
X-4	28 days	7625.0	7619.3	5.7	2.381	2.39
(7 Bag Reference,	6 months	7560.7	7556.0	4.7	2.346	2.00
CA-2, Fa-1b)	12 months	7502.7	7502.7	5.7	2.335	2.44
X-5	28 days	7019.0	6999.7	19.3	2.260	8.54
(4 Bag Admixture,	6 month	7046.0	7030.0	16.0	2.248	7.12
CA-2, FA-1b)	12 month	6940.7	6930.0	10.7	2.246	4.90
X-6	28 days	7125.0	7108.7	16.3	2.268	7.19
(5 Bag Admixture,	6 months	6989.0	6979.0	10.0	2.243	4.49
CA-2, FA-1b)	12 months	7024.0	7016.3	7.7	2.242	3.43
X-7	28 days	7289.7	7277.4	12.3	2.276	5.40
(6 Bag Admixture,	6 months	6974.7	6966.4	8.3	2.270	3.66
CA-2, FA-1b)	12 months	7042.0	7034.3	7.7	2.256	3.41
X-8	28 days	7180.3	7169.0	11.3	2.279	4.96
(7 Bag Admixture,	6 months	7114.0	7169.0	3.7	2.273	1.63
CA-2, FA-1b)	12 months	7235.7	7230.0	5.7	2.258	2.52

APPENDIX B
PHASE II

TABLE 6

PHYSICAL PROPERTIES OF AGGREGATES

GRADATION

Coarse Aggregate					Fine Aggregate	
U. S. Sieve	CA-1	CA-2	CA-3	CA-4	U. S. Sieve	FA-1
	Percent Passing					Percent Passing
1 1/2 inch	100	100		100	3/8 inch	100
1 inch		99		99	No. 4	98
3/4 inch	75	91	100	91	No. 8	91
1/2 inch	30	59	93	59	No. 16	80
3/8 inch		37	72	37	No. 30	64
No. 4	0	9	8	9	No. 50	20
No. 8		2	2	2	No. 100	2
					Sand Equivalent	92.9

UNIT WEIGHT, SPECIFIC GRAVITY, SOUNDNESS AND ABRASION LOSS

Unit wt. lb/cu. ft. Rodded	95.5	95.5	43.6	98.6		113.0
Unit wt. lbs/cu ft. Loose	89.5	89.5	39.6	91.4		106.0
Bulk SSD Specific Gravity	2.54	2.54	1.39	2.48		2.61
Soundless Loss Magnesium Sulf. %	3.30	3.30	7.66	9.52		2.96
Los Angeles Abrasion Loss Grade B %	19.8	19.8	30.5	20.1		

TABLE 7 (Cont.)

CONCRETE MIX DATA

Mix Identification	Aggregate Identification		Mix Designs						Mix Data			
	Coarse Aggregate	Fine Aggregate	Cement lbs.	Coarse Aggregate lbs.	Fine Aggregate lbs.	Water gals.	Water Reducer oz/bag	Air Entraining ozs./bag	Slump inch	Air Content %	Fresh Unit Weight lbs./cu.ft.	Actual Cement Content Bags/cu.yd.
R-17	CA-4	FA-1	94	496	309	8.250	---	---	3	1.3	143.6	4.00
A-18	CA-4	FA-1	94	496	294	6.930	6.0	1/4	3 1/4	4.6	138.0	3.96
R-19	CA-4	FA-1	94	388	241	6.600	---	---	3 1/4	1.3	144.0	4.99
A-20	CA-4	FA-1	94	388	228	5.610	6.0	1/2	3 3/4	4.7	138.4	4.94
R-21	CA-4	FA-1	94	315	196	5.500	---	---	3 3/4	1.2	144.8	5.99
A-22	CA-4	FA-1	94	315	184	4.730	6.0	1/2	3 3/4	4.7	138.8	5.92
R-23	CA-4	FA-1	94	262	163	4.857	---	---	3 1/2	1.3	145.6	7.02
A-24	CA-4	FA-1	94	262	150	4.274	6.0	2/3	3 3/4	4.2	139.6	6.96
L-25	CA-3	FA-1	94	157	256.5	11.04	6.0	3/4	3 3/4	7.7	110.4	4.97
L-26	CA-3	FA-1	94	125	203.5	9.28	6.0	1.0	3 3/4	7.6	111.6	6.05
L-27	CA-3	FA-1	94	103	168.0	8.04	6.0	1.0	3 3/4	7.2	112.8	7.07
R-28			Test on Concrete Mixes before			8.050	---	---	3	1.2	145.2	3.99
A-29			being screened over a No. 4			8.762	6.0	1/2	3 1/4	4.0	140.8	3.99
R-30			sieve.			6.400	---	---	3	1.3	146.0	4.99
A-31	CA-1	FA-1				5.440	6.0	1/2	3	3.9	140.8	4.95
R-32			Mix design same as all			5.333	---	---	3 1/4	1.2	146.4	6.00
A-33			CA-1 mixes			4.586	6.0	2/3	3 1/4	3.7	142.0	5.99
R-34						4.714	---	---	3 3/4	1.2	146.4	6.98
A-35						4.148	6.0	1.0	3 3/4	4.1	141.2	6.96

TABLE 8

AVERAGE MONTHLY TEMPERATURES FROM DAILY RECORDINGS

				Average	
Month	Year	High	Low	High	Low
October	1966	93°F	43°F	83°F	55°F
November	1966	91°F	30°F	78°F	52°F
December	1966	83°F	27°F	64°F	44°F
January	1967	82°F	32°F	65°F	44°F
February	1967	78°F	27°F	66°F	42°F
March	1967	97°F	40°F	81°F	54°F
April	1967	99°F	52°F	89°F	62°F
May	1967	101°F	52°F	90°F	63°F
June	1967	107°F	63°F	100°F	68°F
July	1967	108°F	73°F	101°F	68°F
August	1967	107°F	60°F	97°F	70°F
September	1967	100°F	44°F	92°F	65°F
October	1967	101°F	44°F	85°F	55°F
November	1967	91°F	36°F	78°F	50°F
December	1967	82°F	28°F	65°F	47°F

Note: All Temperatures were taken in the open, not in the shade.

Aggregates CA-1 began 10-4-66 and ended 10-12-67
Aggregates CA-3 began 11-9-66 and ended 11-9-67
Aggregates CA-4 began 11-28-66 and ended 12-1-67
Aggregates CA-2 began 12-6-66 and ended 12-8-67
Mortar Mix Specimens began 10-12-66 and ended 11-3-67

TABLE 9

AVERAGE COMPRESSIVE STRENGTH
AND DYNAMIC MODULUS RESULTS

Mix Identification	Age at Test	Compressive Strength	Dynamic Modulus
	28 days	3038	5,415,985
	6 months	4334	5,443,255
R-1	12 months	4604	5,466,864
	28 days	4140	5,397,177
	6 months	4896	5,689,413
A-2	12 months	4688	5,652,095
	28 days	4416	6,078,833
	6 months	5833	5,952,914
R-3	12 months	5625	5.937,771
	28 days	4858	5,935,865
	6 months	6729	6,373,168
A-4	12 months	5959	6,177,330
	28 days	4870	6,477,367
	6 months	5792	6,519,329
R-5	12 months	6938	6,504,275
	28 days	5064	6,187,457
	6 months	6313	6,395,515
A-6	12 months	7438	6,666,912
	28 days	6207	6,403,028
	6 months	7750	6,699,890
R-7	12 months	7813	6,527,337
	28 days	5807	6,384,480
	6 months	5292	6,807,096
A-8	12 months	8167	6,622,712
	28 days	2568	5,289,711
	6 months	3104	5,304,297
R-9	12 months	4115	5,839,195

* All 6 month, and 12 month compressive strength are 3"x4"x5 1/2" Concrete specimens.

TABLE 9. (Cont.)

AVERAGE COMPRESSIVE STRENGTH
AND DYNAMIC MODULUS RESULTS

Mix Identification	Age at Test	Compressive Strength	Dynamic Modulus
	28 days	3257	5,078,692
	6 months	4229	5,519,389
A-10	12 months	4401	5,631,327
	28 days	3817	5,903,107
	6 months	5334	6,198,898
R-11	12 months	6437	6,053,686
	28 days	4488	5,950,787
	6 months	5333	5,871,707
A-12	12 months	6438	5,758,845
	28 days	6101	6,276,225
	6 months	7917	6,352,395
R-13	12 months	8250	6,613,317
	28 days	5830	6,341,060
	6 months	6479	6,437,219
A-14	12 months	8708	6,367,813
	28 days	6637	6,632,157
	6 months	8687	6,702,046
R-15	12 months	9230	6,467,546
	28 days	6184	6,481,723
	6 months	7959	6,452,587
A-16	12 months	9334	6,550,776
	28 days	2568	5,279,345
	6 months	3709	5,253,959
R-17	12 months	4500	5,312,489
	28 days	2933	4,846,494
	6 months	4230	4,856,980
A-18	12 months	4813	4,978,913

TABLE 9 (Cont.)

AVERAGE COMPRESSIVE STRENGTH AND DYNAMIC MODULUS RESULTS

Mix Identification	Age at Test	Compressive Strength	Dynamic Modulus
	28 days	4358	5,710,669
	6 months	6063	5,770,255
R-19	12 months	6563	5,672,144
	28 days	4099	5,199,266
	6 months	5709	5,287,379
A-20	12 months	6125	5,245,955
	28 days	5769	5,934,073
	6 months	7104	6,127,882
R-21	12 months	8250	5,973,769
	28 days	5277	6.017,096
	6 months	6917	5,982,245
A-22	12 months	6938	6,125,469
	28 days	6655	6,234,012
	6 months	8688	6,422,376
R-23	12 months	9375	6,467,293
	28 days	5919	5,754,941
	6 months	8292	5,911,712
A-24	12 months	8854	6,220,951
	28 days	3846	2,688,993
	6 months	4417	2,850,055
L-25	12 months	5188	2,996,492
	28 days	4912	2,906,989
	6 months	5000	2,976,044
L-26	12 months	6188	3,230,336
	28 days	5401	3,164,687
	6 months	4375	3,207,964
L-27	12 months	6292	3,183,070

TABLE 10 (Cont.)
AVERAGE WEAR TEST EVALUATION RESULTS

Concrete Mix Description	Age at Test	Wt. before test, W_1, gr.	Wt. after test, W_2, gr.	Wt. of Abraded Material, W, gr.	Bulk Specific Gravity (SSD)	Loss on Abrasion Cu. cm. Per sq. cm.
A-8	28 days	7383.7	7372.7	11.0	2.333	0.09
(7 bag Admixture	6 months	7327.5	7318.0	9.5	2.326	0.08
CA-1, FA-1)	12 months	7274.5	7269.5	5.0	2.315	0.04
R-9	28 days	7397.3	7375.3	22.0	2.351	0.18
(4 bag Reference	6 months	7277.0	7260.0	17.0	2.359	0.14
CA-2, FA-1)	12 months	7591.5	7582.0	9.5	2.355	0.08
A-10	28 days	7058.3	7041.7	16.6	2.237	0.14
(4 bag Admixture	6 months	7170.5	7157.5	13.0	2.274	0.11
CA-2, FA-1)	12 months	7169.0	7162.0	7.0	2.265	0.06
R-11	28 days	7352.0	7337.0	15.0	2.366	0.12
(5 bag Reference	6 months	7390.5	7380.0	10.5	2.366	0.09
CA-2, FA-1)	12 months	7467.0	7463.5	3.5	2.352	0.03
A-12	28 days	7293.7	7279.7	14.0	2.289	0.12
(5 bag Admixture	6 months	7173.0	7164.0	9.0	2.276	0.08
CA-2, FA-1)	12 months	6978.0	6972.0	6.0	2.264	0.05
R-13	28 days	7414.0	7403.0	11.0	2.378	0.09
(6 bag Reference	6 months	7288.5	7280.0	8.5	2.375	0.07
CA-2, FA-1)	12 months	7296.0	7290.0	6.0	2.357	0.05
A-14	28 days	7279.7	7268.3	11.4	2.312	0.10
(6 bag Admixture	6 months	7302.5	7292.5	10.0	2.307	0.08
CA-2, FA-1)	12 months	7270.0	7263.5	6.5	2.298	0.05

TABLE 10 (Cont.)
AVERAGE WEAR TEST EVALUATION RESULTS

Concrete Mix Description	Age at Test	Wt. before test, W_1, gr.	Wt. after test, W_2, gr.	Wt. of Abraded Material, W. gr.	Bulk Specific Gravity (SSD)	Loss on Abrasion Cu. cm. Per sq. cm.
R-15	28 days	7493.0	7482.3	10.7	2.397	0.09
(7 bag Reference	6 months	7377.5	7368.5	9.0	2.374	0.07
CA-2, FA-1)	12 months	7384.0	7379.5	4.5	2.364	0.04
A-16	28 days	7318.3	7308.0	10.3	2.334	0.09
(7 bag Admixture	6 months	7186.5	7177.5	9.0	2.323	0.08
CA-2, FA-1)	12 months	7224.0	7219.0	5.0	2.315	0.04
R-17	28 days	7427.3	7409.3	18.0	2.332	0.15
(4 bag Reference	6 months	7222.5	7206.5	16.0	2.339	0.13
CA-4, FA-1)	12 months	7472.5	7460.5	12.0	2.327	0.10
A-18	28 days	6964.3	6947.3	17.0	2.248	0.15
(4 bag Admixture	6 months	6870.5	6855.5	15.0	2.242	0.13
CA-4, FA-1)	12 months	6847.0	6833.5	13.5	2.231	0.12
R-19	28 days	7389.7	7379.0	10.7	2.339	0.09
(5 bag Reference	6 months	7287.0	7278.5	9.5	2.334	0.08
CA-4, FA-1)	12 months	7149.5	7142.0	7.5	2.245	0.06
A-20	28 days	6941.0	6928.0	13.0	2.240	0.11
(5 bag Admixture	6 months	6861.0	6852.0	9.0	2.228	0.08
CA-4, FA-1)	12 months	6814.0	6805.5	8.5	2.215	0.07
R-21	28 days	7346.7	7336.7	10.0	2.354	0.08
(6 bag Reference	6 months	7229.5	7222.5	7.0	2.347	0.06
CA-4, FA-1)	12 months	7110.0	7107.5	2.5	2.321	0.02

TABLE 10 (Cont.)
AVERAGE WEAR TEST EVALUATION RESULTS

Concrete Mix Description	Age at Test	Wt. before test W_1, gr.	Wt. after test W_2, gr.	Wt. of Abraded Material, W. gr.	Bulk Specific Gravity (SSD)	Loss on Abrasion Cu. cm. Per sq. cm.
A-22	28 days	7230.3	7219.3	11.0	2.283	0.09
(6 bag Admixture	6 months	7150.5	7150.5	8.5	2.269	0.07
CA-4, FA-1)	12 months	7124.0	7119.0	5.0	2.261	0.04
R-23	28 days	7346.3	7338.7	7.6	2.363	0.06
(7 bag Reference	6 months	7370.0	7364.5	9.5	2.350	0.08
CA-4, FA-1)	12 months	7309.5	7306.0	3.5	2.335	0.03
A-24	28 days	7109.7	7101.0	8.7	2.295	0.07
(7 bag Admixture	6 months	7004.0	6998.0	6.0	2.287	0.05
CA-4, FA-1	12 months	7156.5	7152.0	4.5	2.273	0.04
L-25	28 days	5315.7	5302.3	13.4	1.735	0.15
(5 bag Admixture	6 months	5336.5	5324.5	12.0	1.720	0.14
CA-3, FA-1)	12 months	5480.0	5469.0	11.0	1.697	0.13
L-26	28 days	5454.0	5442.0	12.0	1.768	0.13
(6 bag Admixture	6 months	5358.5	5348.5	10.0	1.748	0.11
CA-3, FA-1)	12 months	5507.0	5500.0	7.0	1.772	0.08
L-27	28 days	5566.6	5656.3	10.3	1.810	0.11
(7 bag Admixture	6 months	5512.5	5504.0	8.5	1.777	0.09
CA-3, FA-1)	12 months	5480.5	5474.0	6.5	1.753	0.07

TABLE 10 (Cont.)
AVERAGE WEAR TEST EVALUATION RESULTS

Mortar Mix Description	Age at Test	Wt. before test, W_1, gr.	Wt. after test W_2, gr.	Wt. of Abraded Material, W. gr.	Bulk Specific Gravity (SSD)	Loss on Abrasion Cu. cm. Per sq. cm.
R-28	28 days	6770.6	6750.6	20.0	2.219	0.17
(4 bag Reference	6 months	6759.7	6744.0	15.7	2.217	0.14
CA-1, FA-1)	12 months	6816.0	6804.3	11.7	2.205	0.10
A-29	28 days	6716.3	6701.0	15.3	2.117	0.14
(4 bag Admixture	6 months	6477.3	6466.0	11.3	2.104	0.10
CA-1, FA-1)	12 months	6513.3	6505.8	7.5	2.091	0.07
R-30	28 days	7299.6	7987.7	11.9	2.253	0.10
(5 bag Reference	6 months	6902.6	6896.7	5.9	2.235	0.05
CA-1, FA-1)	12 months	6779.7	6773.7	6.0	2.210	0.05
A-31	28 days	6747.7	6736.7	11.0	2.173	0.10
(5 bag Admixture	6 months	6660.0	6652.7	7.3	2.157	0.07
CA-1, FA-1)	12 months	6595.2	6590.8	4.4	2.138	0.04
R-32	28 days	7024.7	7015.0	9.7	2.268	0.08
(6 bag Reference	6 months	6877.0	6869.0	8.0	2.252	0.07
CA-1, FA-1)	12 months	6905.0	6902.0	3.0	2.235	0.03
A-33	28 days	6770.0	6760.3	9.7	2.208	0.09
(6 bag Admixture	6 months	6824.3	6815.7	8.6	2.196	0.08
CA-1, FA-1)	12 months	6809.3	6807.8	1.5	2.181	0.01
R-34	28 days	6976.0	6964.0	12.0	2.284	0.10
(7 bag Reference	6 months	6982.0	6976.5	5.5	2.270	0.05
CA-1, FA-1)	12 months	7046.3	7014.8	4.5	2.256	0.04