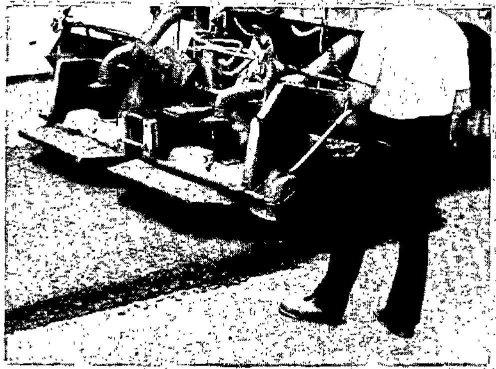
Report No. FHWA-RD-78-144

THREE YEAR RESULTS ON THE PERFORMANCE OF INCINERATOR RESIDUE IN A BITUMINOUS BASE

DEPARTMENT OF TRANSPORTATION • UNITED STATES OF AMERICA



August 1978
Interim Report

Reprinted June 1979

Prepared for

FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
Washington, D.C. 20590

FOREWORD

This report describes laboratory and field evaluations of an experimental bituminous base mix using incinerator residue as aggregate which was placed during 1974 in Houston, Texas. An adjacent conventional bituminous concrete pavement was also constructed and evaluated as a control section. Both 6 inch base test sections were covered with 1½ inches of standard bituminous concrete wearing surface. After 4 years of service the results indicate that the incinerator residue test base is performing in an excellent manner and as well as the control base.

This publication is being distributed to bituminous technologists and will be made available to anyone interested in the new concepts developed on the use of incinerator residue waste as highway material. This report is the second in a series to result from this continuing research being conducted by the Texas Transportation Institute for the Federal Highway Administration.

The assistance of the City of Houston in this study is gratefully acknowledged.

Charles F. Scheffey

Charles F. Scheffey
Director, Office of Research

NOTICE

Technical Report Documentation Page

1. Report No. FHWA-RD-78-144	2. Government Accession No.	3. Recipient's Catalog No. PB297978

4. Title and Subtitle

THREE YEAR RESULTS ON THE PERFORMANCE OF INCINERATOR RESIDUE IN A BITUMINOUS BASE

5. Report Date
August, 1978

6. Performing Organization Code

7. Author(s)
D. J. Teague and W. B. Ledbetter

8. Performing Organization Report No.
RF 968-2

9. Performing Organization Name and Address
Texas Transportation Institute
Texas A&M University
College Station, Texas 77843

10. Work Unit No. (TRAIS)
FCP 34C1-024

11. Contract or Grant No.
DOT-FH-11-8027

12. Sponsoring Agency Name and Address
Office of Research and Development
Federal Highway Administration
U. S. Department of Transportation
Washington, D.C. 20590

13. Type of Report and Period Covered
SECOND INTERIM REPORT
June 1974 - October 1977

14. Sponsoring Agency Code
~~M-0208~~ M/0566

15. Supplementary Notes
FHWA Contract Managers: W. Clayton Ormsby (HRS-23) and Charles A. Pagen (HRS-23)
FHWA Implementation Manager: W. C. Besselievre (HDV-22)

16. Abstract

The use of incinerator residue as an aggregate in a bituminous base (termed littercrete) was studied. Test sections consisting of the experimental hot mixed littercrete base and a conventional hot mixed asphaltic concrete base (termed blackbase control) and topped with a conventional surface were placed on a city street in Houston, Texas. This report presents the results from observations and tests on cores during the first three years of in service performance.

Results of the laboratory and field evaluations show that the littercrete section is performing in an excellent manner, almost identical with the conventional blackbase control section. The only distress that has occurred is minor cracking in both sections. This cracking is limited to the conventional wearing surface and has not progressed into the bases.

17. Key Words Incinerator Residue, Solid Waste, Blackbase, Asphaltic Concrete Pavement, Experimental Pavement	18. Distribution Statement No restriction. This document is available through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 69	22. Price PC A04/MF A01

Form DOT F 1700.7 (8-72)   Reproduction of completed page authorized

Table of Contents

LIST OF ABBREVIATIONS AND SYMBOLS

Symbol	Definition or Description	Unit
M_R	resilient modulus	psi (kPa)
σ_T	ultimate strength	psi (kPa)
r	correlation coefficient	

List of Figures

List of Figures (Cont.)

List of Tables

1.0 Introduction

1.1 Background

The construction and maintenance of the United States' ever expanding highway system has created an increasing demand for quality construction materials. In terms of materials production, the strong lead which the United States enjoyed over other industrialized nations since the early 1950's has steadily diminished.(1)

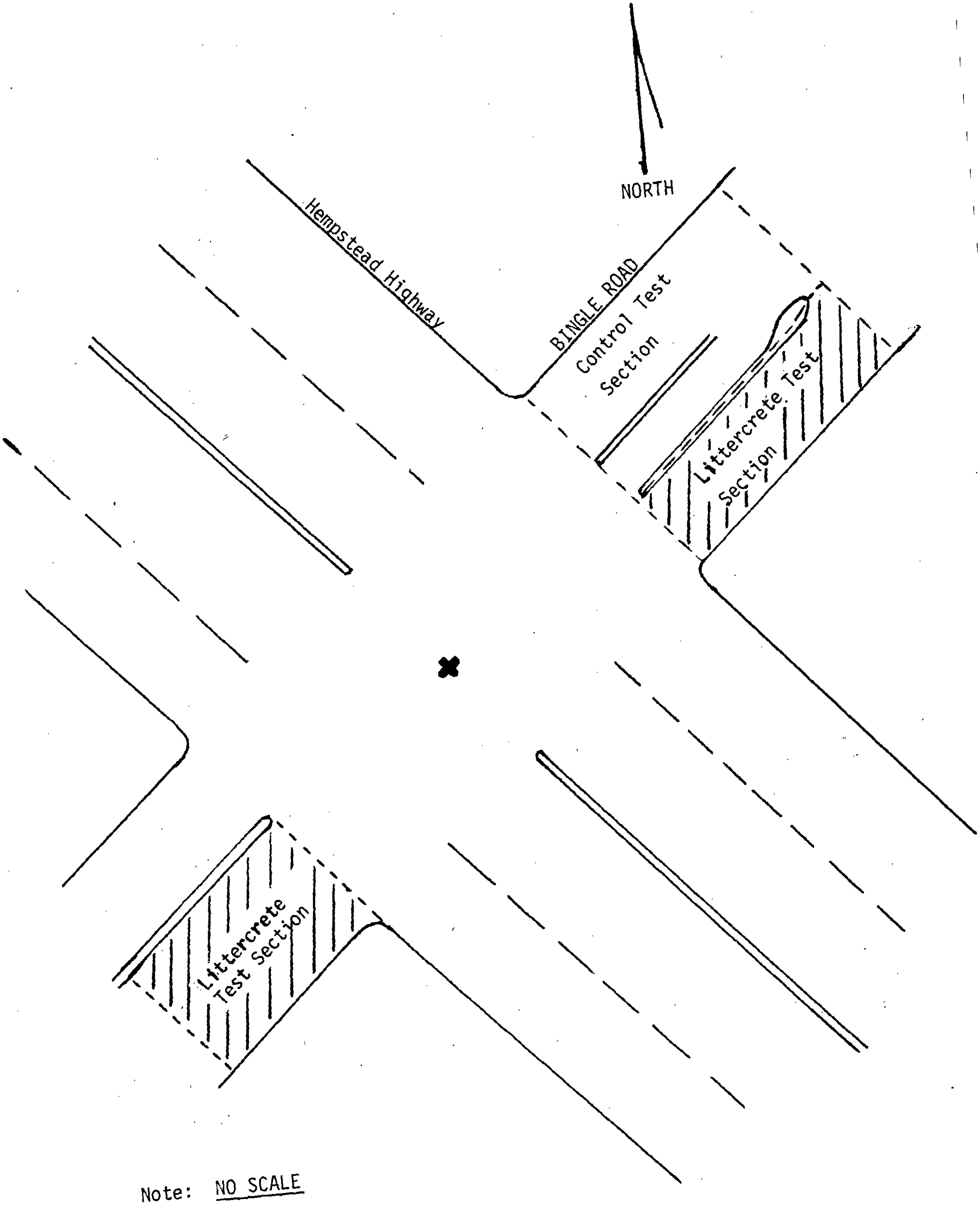
While there is an abundant supply of source materials for the production of quality aggregates for the foreseeable future(2) the distribution of these sources does not always coincide with the location of need. This has increased the cost and the energy consumed in constructing transportation facilities. Attempts have been made to develop supplemental aggregate sources, economically and realistically, in an effort to fulfill localized demands. One such aggregate source being investigated is incinerator residue obtained from the burning of municipal solid wastes. The feasibility of using solid wastes in highway construction and maintenance has been investigated by the Texas Transportation Institute.(3) Several potential uses of solid wastes were studied including its use as an aggregate replacement for base, subbase, and stabilized materials. This report is concerned with the four year in-service evaluation of municipal solid waste taken directly from an incinerator and used as an aggregate replacement in bituminous base construction on a city street.

1.2 Objective

The objective of this study was to determine the usefulness of municipal residue as an aggregate in bituminous base construction (termed littercrete in this study).

1.3 Scope

The work consisted of construction, control and evaluation of approximately 200 ft (60 m) of roadway on Bingle Road at the intersection of the old Hempstead Highway in Houston, Texas, Figure 1. This test section, contracted by



Note: NO SCALE

Figure 1 Sketch of test section site

the City of Houston, and constructed in 1974 by Brown & Root, Inc., consisted of municipal incinerator residue from Houston's Holmes Road incinerator plant as the aggregate in a 6 in. (15.2 cm) thick bituminous base (termed littercrete) which was covered by approximately 1½ in. (3.8 cm) of a conventional hot-mixed asphaltic concrete wearing surface. For comparison purposes a conventional aggregate bituminous base (termed blackbase control), situated adjacent to the test section, was constructed and evaluated. The evaluation period was four years.

1.4 Conclusions

1. Based on evaluation of recovered asphalt samples, the asphalt in both the littercrete and the control section is performing essentially the same in service.

2. Based on visual examinations of the pavement surface and cores, as well as the densities of the cores, the littercrete section, after three years in service, is performing as well as the blackbase control section. No rutting or shoving has occurred.

3. Laboratory results of strength, as determined by Marshall stability and splitting tensile strength values, verify the observation that the littercrete is performing as well as the blackbase control.

4. Laboratory results of the Hveem stability indicate the littercrete section has lost more stability than the black base control. The implications of these results are not known.

5. Laboratory results of the Resilient Modulus test indicate after three years in service the littercrete is performing essentially the same as when it was constructed while the control section has "hardened".

1.5 Recommendations

While the different test results indicate that the littercrete section is performing satisfactorily and should remain satisfactory for a long period of time, it is our recommendation that the test sections be observed and evaluated at one year intervals for another three years. After this additional three year evaluation period, another report should be prepared. With a potentially valuable aggregate substitute such as incinerator residue being tried, it is important to see if the littercrete test section does indeed continue to perform in a satisfactory manner.

2.0 Materials

2.1 Asphalt

The asphalt used throughout this study was an AC-20 grade asphalt cement, refined at Exxon's Baytown, Tex., refinery. Standard asphalt tests and asphalt extractions were performed on laboratory and field samples from both the littercrete and control sections during the three year evaluation period (Table 1). During the period of evaluation the viscosity of the recovered asphalt has increased and the penetration of the recovered asphalt has decreased. "Hardening" of the asphalt is a normal expectation due to oxidation and other forces on the asphalt. From the table it is apparent that the asphalt in each section is performing essentially the same in service.

2.2 Aggregate

The aggregate consisted of municipal residue from the Holmes Road Incinerator Plant in Houston, Texas. A typical sample of this aggregate was compared to a Texas Class A-Type C grading specification (Figure 2) and was found to be within specifications except in the range of minus No. 30 (60μm) to minus No. 200 (75μm). The aggregate was found to contain appreciable fines which were not noticeable in the dry sieve analysis. When wet sieve analysis was conducted the aggregate was found to meet the Texas specifications.

2.3 Mix Proportion

Trial mixes consisting of 9, 10, and 11 percent asphalt by total weight of mix were mixed in the laboratory, compacted and tested to determine the optimum asphalt content of the mix. A discussion of the mix procedure, sample preparation, and test procedures used in the optimum mix design are given in the first report of this study. The seemingly high asphalt contents are due primarily to the low specific gravity of the aggregate (average of 2.13). Based on the results obtained, the recommended optimum mix design consisted of:

Table 1. Asphalt Properties Summary.[a]

		Laboratory Compacted		Field Compacted Cores			
	Exxon	Cores		New[b]		Six-Months[c]	
	AC 20	Littercrete	Control	Littercrete	Control	Littercrete	Control
Penetration							
39.2°F	16	29	19	10	18	11	15
77°F	54	45	54	27	41	32	37
Viscosity - Poise							
77°F	2.3×10^6	4.2×10^6	4.5×10^6	12.4×10^6	3.2×10^6	7.0×10^6	7.0×10^6
140°F	2606	4982	2916	--	--	--	--
275°F	3.7	4.4	3.9	6.1	4.3	4.8	4.5
Softening Point °F	124	130-131	128-129	137-139	126	134-135	130-132
Specific Gravity[d]	1.02	1.02	1.02	--	--	--	--
Recovered % Asphalt Content[e]	--	9.9	4.6	9.2	5.3	10.8	5.3

a) Average of samples per test value
b) Taken immediately after construction
c) Taken after six months in service
d) 77°F
e) Mix basis, 9% by wt core samples taken from approximately the same place in the road

$$t^{\circ}_{C} = \frac{(t^{\circ}_{F} - 32)}{1.8}$$

Table 1. Asphalt Properties Summary (Continued)

	Field Compacted Cores					
	ONE-YEAR^{d}		TWO-YEARS^{e}		THREE-YEARS^{f}	
	Littercrete	Control	Littercrete	Control	Littercrete	Control
Penetration						
39.2 °F	10	8	3	13	6	8
77 °F	28	24	22	56	30	33
Viscosity - Poise						
77 °F	11×10^{6}	24.4×10^{6}	—	—	10.5×10^{6}	9.62×10^{6}
140 °F	—	—	—	—	—	—
275 °F	5.5	6.6	7.2	4.8	5.79	5.39
Softening Point °F	134	144	—	—	139	133
Specific Gravity^{b}	—	—	—	—	—	—
Recovered Asphalt Content^{c}	9.7	4.9	9.4	5.2	9.5	5.1

a) Average of samples per test value

b) 77°F

c) Mix basis, 9% by wt core samples taken from approximately the same place in the road.

d) Taken after one year in service

e) Taken after two years in Service

f) Taken after three years in service

$$t°c = \frac{(t°f - 32)}{1.8}$$

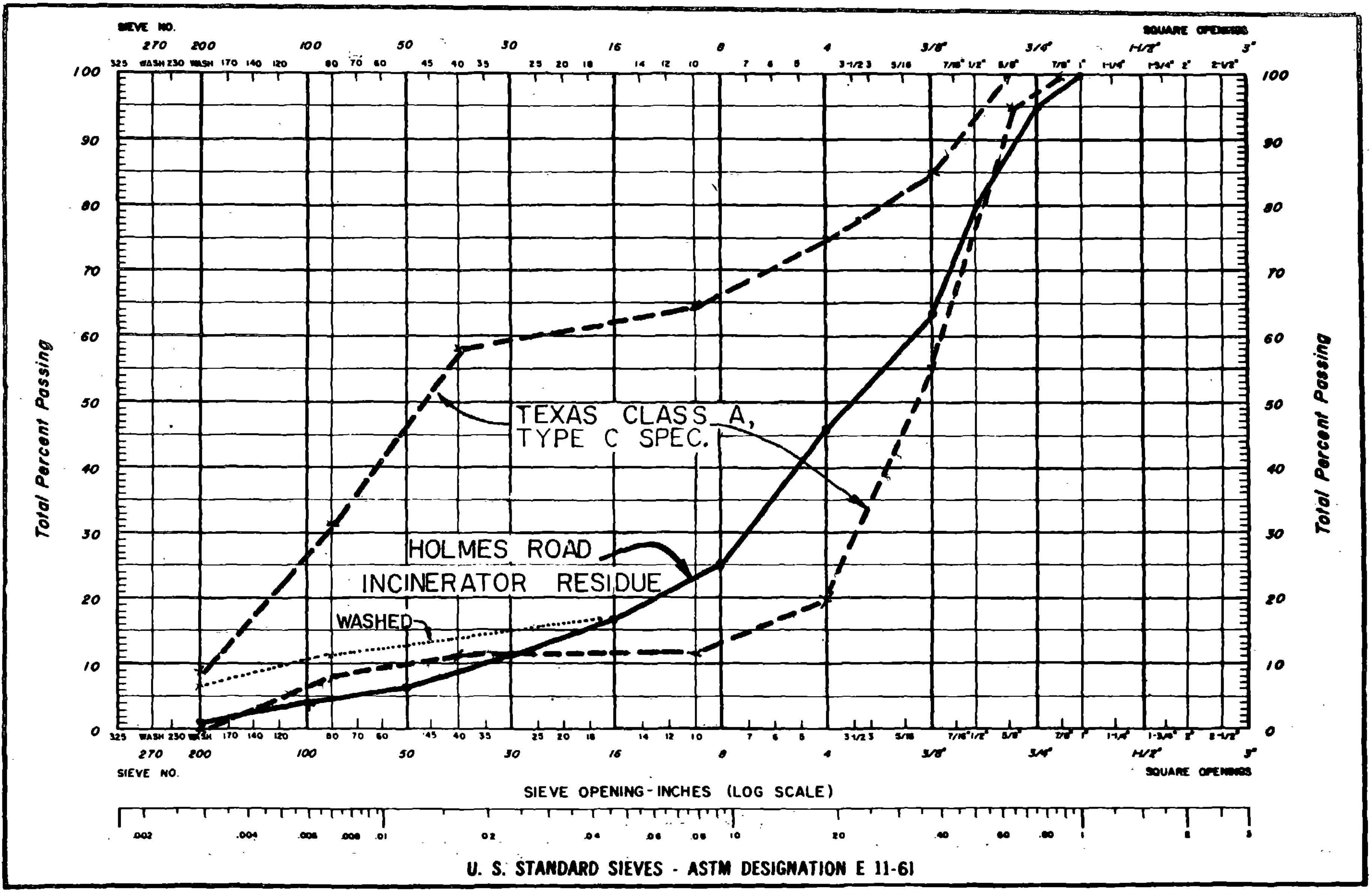


Figure 2 Aggregate gradation chart showing incinerator residue in relation to Texas Class A Type C gradation specification.

Material	Percent by Total Volume	Percent by Total Weight of Mix	Equivalent Percent[a] By Total Weight Mix
Incinerator Residue	80.9	89.0	91.0
Asphalt AC-20	17.4	9.0	7.4
Hydrated Lime	1.7	2.0	1.6

[a] Equivalent percent by total weight of mix assuming the aggregate had a specific gravity of 2.65.

3 Construction Sequence

Construction began in July 1974. Approximately 600 yd^3 (460 m^3) of incinerator residue were stockpiled at the Holmes Road Incinerator Plant. The residue was spread into a 1 ft (0.3 m) thick lift and bulk, hydrated lime was added to the residue at the approximate rate of 2% lime by dry weight of the material (to prevent asphalt stripping from the glass in the residue). Water was added and the residue and lime mixed to a depth of approximately 8 in. (200 mm).

The residue (with lime) was loaded into end dump trucks, hauled to an asphalt plant, and run through a conventional pug mill at 300°F (150°C). The material was then transported to the construction site and placed into a conventional asphaltic concrete laydown machine. The material was placed in two 3 in. (76 mm) lifts over 6 in. (150 mm) of lime-stabilized subgrade, and each lift was compacted with tandem, steel wheel rollers, and pneumatic rollers. Finally, a 1½ in. (38 mm) conventional asphaltic concrete wearing surface was placed over the base material. After the pavement had cooled sufficiently, 4 in. (100 mm) diameter base cores were taken for testing purposes. Coring was repeated at ages of 6 months, one year, two years, and three years.

A control section placed adjacent to the littercrete section consisted of 1½ in.(38 mm) maximum size limestone aggregate, natural sand fine aggregate, and 6% asphalt (by total weight of the mix). The design used is typical of pavement systems for the City of Houston, Texas.

4.0 Field Observations

Visual examinations of the pavement sections were taken monthly for the first six months in service and at three month intervals thereafter. These visual examinations were performed to observe the two pavement sections for evidence of cracking or noticeable failure. After two years in service small longitudinal cracks 3/16 in. (.476 cm) to 1/4 in. (635 cm) in size were noticed in both the littercrete and control sections (Figure 3, page 10). During the third year observation period it was noticed that although there were slightly more cracks, the cracks had not increased in size. At this time a core sample was taken from the cracked section to determine the depth of penetration of the crack.

The cracks were found to be in the wearing surface only Figure 4, page 10) and are believed to have been caused by shrinkage of the wearing surface due to temperature changes. These field observations indicate that the littercrete is performing in an excellent manner carrying the traffic and withstanding environmental effects very well. No rutting or shoving has occurred.

A traffic count was taken in 1973 at the test section with results shown in Table 2, page 11. The number of 18 kip (81,700 kg) equivalent axle loads per day the test section would experience in 1973 is 170. Of this traffic it was found that approximately 78% was cars, 19% pickups, 2% single unit trucks and 1% heavy trucks. If a growth rate of 5% per year is assumed, in the three year period the test section would have been subjected to around 200,000-18 kip (81,700 kg) equivalent axle loads.

5.0 Laboratory Investigation

5.1 General

Laboratory investigations conducted in this study were performed on the littercrete and the adjacent control test section to:

1. Compare the littercrete and control mix properties.
2. Quantify the performance of the two pavement sections with time.

Field cores were drilled using a trailer-mounted rig and a 4 in. (10.2 cm) diamond-tipped core barrel. Various testing methods were utilized and the test results are recorded in the appendicies of this report.

Figure 3 Picture of longitudinal crack in littercrete section.

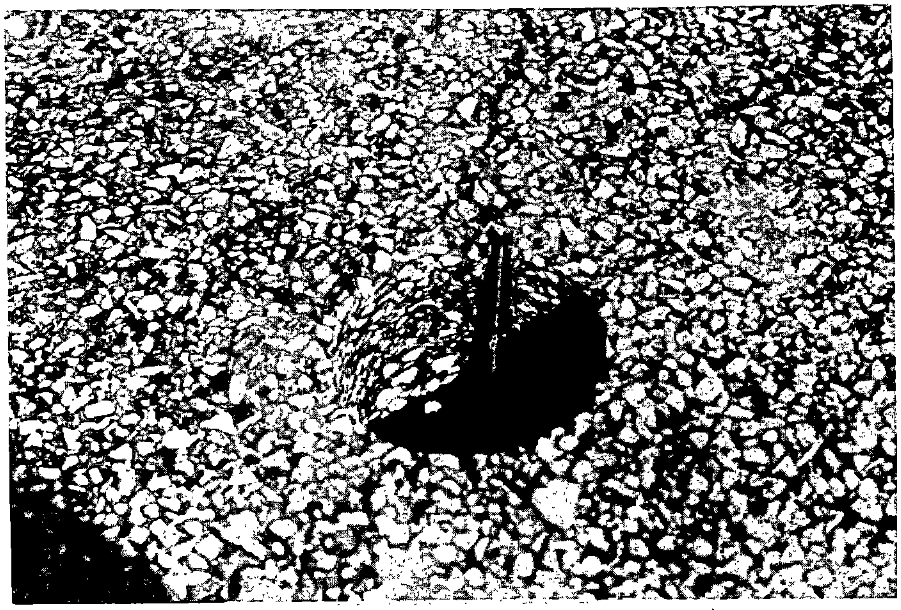


Figure 4 Picture of cracked wearing surface.

Table 2 1973 Traffic Data (Bingle Road at Hempstead Highway).

	Vehicles Per Day			
	Inbound	%	Outbound	%
Cars	4,362	80	3,677	76
Pick-ups	984	17	1,027	21
Single Unit Trucks	94	02	84	02
Heavy Trucks More than 2 axles or 2 tires on read	26	01	39	01
TOTAL	5,466	100	4,827	100

Average 18-kip equivalent axle loads per day - 170

Yearly 18-kip equivalent axle loads - 62,100

1 kip = 4540 kg

The testing program followed on the cores is given in Figure 5. The procedure for the different tests performed and means of data reduction involved can be found in the first report on this study.(9) Also given in the first report are the data used in the graphs and tables involving laboratory, field and six month field compacted samples.

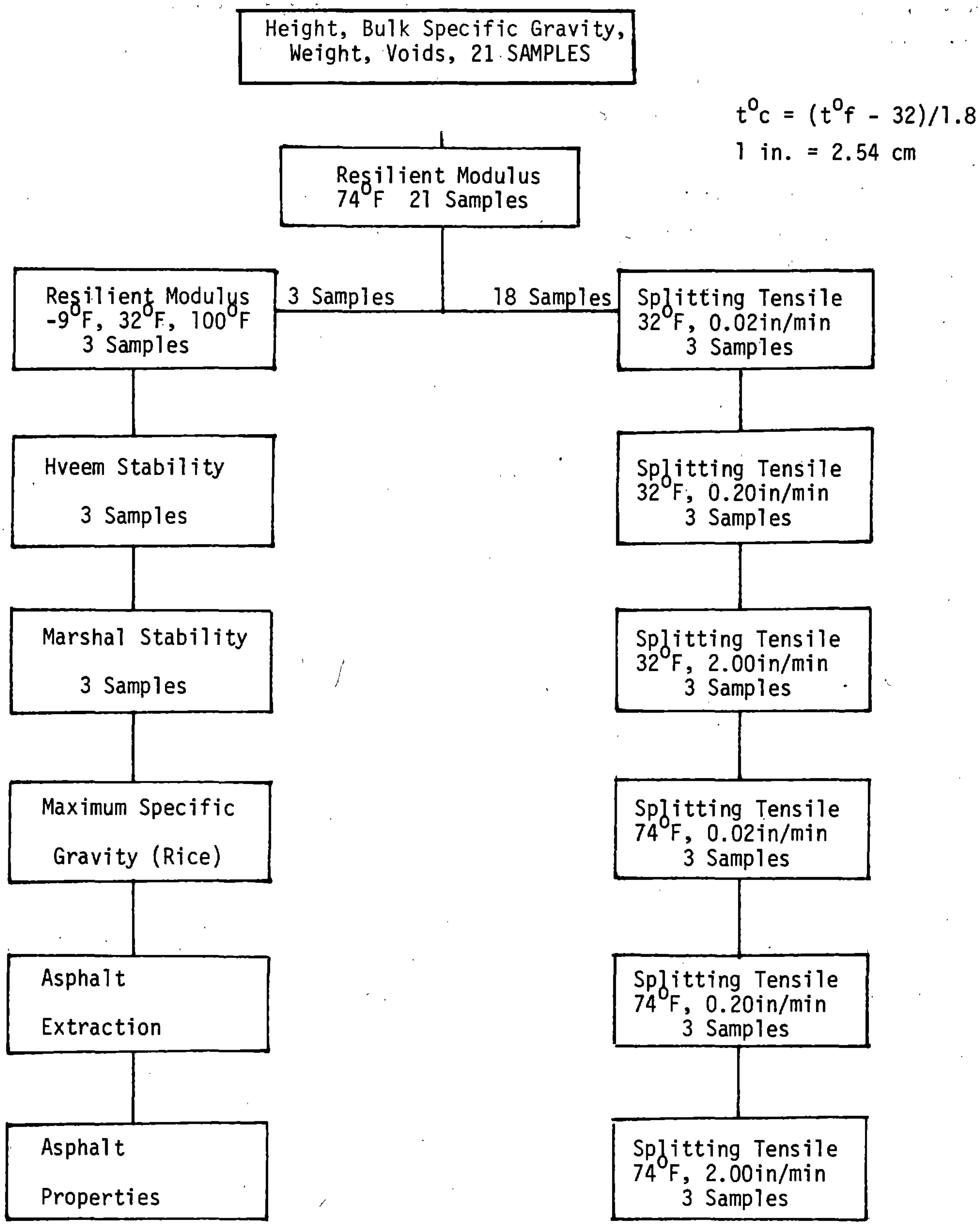
A summary of the results of the tests performed is given in the appropriate sections which follow. Whenever possible the methods used in reducing and presenting the data are similiar to the methods used by other investigators as indicated in the literature. Linear regression equations and correlation coefficients are given for the least square regression lines, using small sample theory. Confidence intervals of 90 percent are given as applicable.

5.2 Specific Gravity

Some problems were associated with determination of the specific gravities of the cores of littercrete. Due to the hetrogeneity of the residue it was difficult to obtain representative samples of the mix. Samples of apparently similar gradation varied in composition which resulted in data scatter of the results. The Maximum Specific Gravity of the core samples (ASTM D2041)(10) was modified slightly to allow the use of a larger test sample which helped to reduce the amount of variability in results. The maximum specific gravity of the different core specimens are summarized in Table 3. As expected, some increase of specific gravity with time was experienced, probably due to densification of the aggregates in the asphaltic concrete.

5.3 Stability

Stability tests performed on the test samples consisted of the Hveem Stabilometer test and Marshall test. (9,10,11) A summary of these data are given in Figure 6 and Figure 7 with the individual data given in Appendix A. The six months field compacted Marshall Stability samples are very low in relation to the other samples which could be caused by testing of a bad sample. The minimum criteria for coarse aggregate type, hot plant mixes in the state of Texas for AC 20 and AC 10 is a Hveem stability of 30(13). When placed both mixes satisfied the Hveem criteria for base courses. The minimum Marshall Stability recommended by the Asphalt In-



$t^{o}c = (t^{o}f - 32)/1.8$

1 in. = 2.54 cm

Figure 5 Testing Program for Core Samples

Table 3 Maximum Specific Gravity[a]

Material	Maximum Specific Gravity
Laboratory Compacted	
CONTROL	2.20
LETTERCRETE	2.04
Field Compacted	
CONTROL	2.24
LITTERCRETE	2.10
Six Months Field Compacted	
CONTROL	2.43
LITTERCRETE	2.06
ONE YEAR Field Compacted	
CONTROL	2.37
LITTERCRETE	2.13
TWO YEAR Field Compacted	
CONTROL	2.38
LITTERCRETE	2.14
THREE YEAR Field Compacted	
CONTROL	2.43
LITTERCRETE	2.13

[a] ASTM Designation D2041

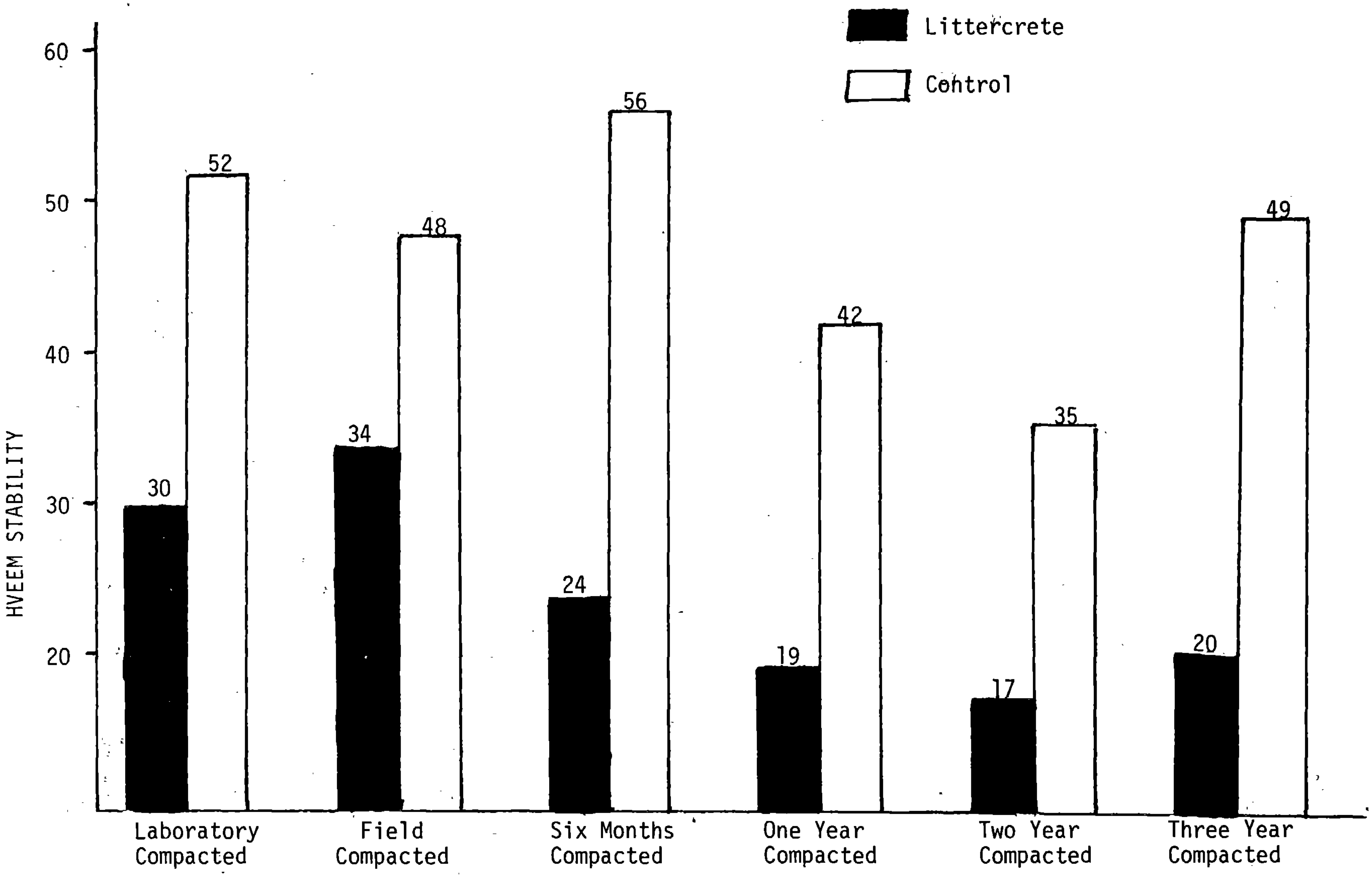


Figure 6 Bar graph showing Hveem Stability values for various times in service.

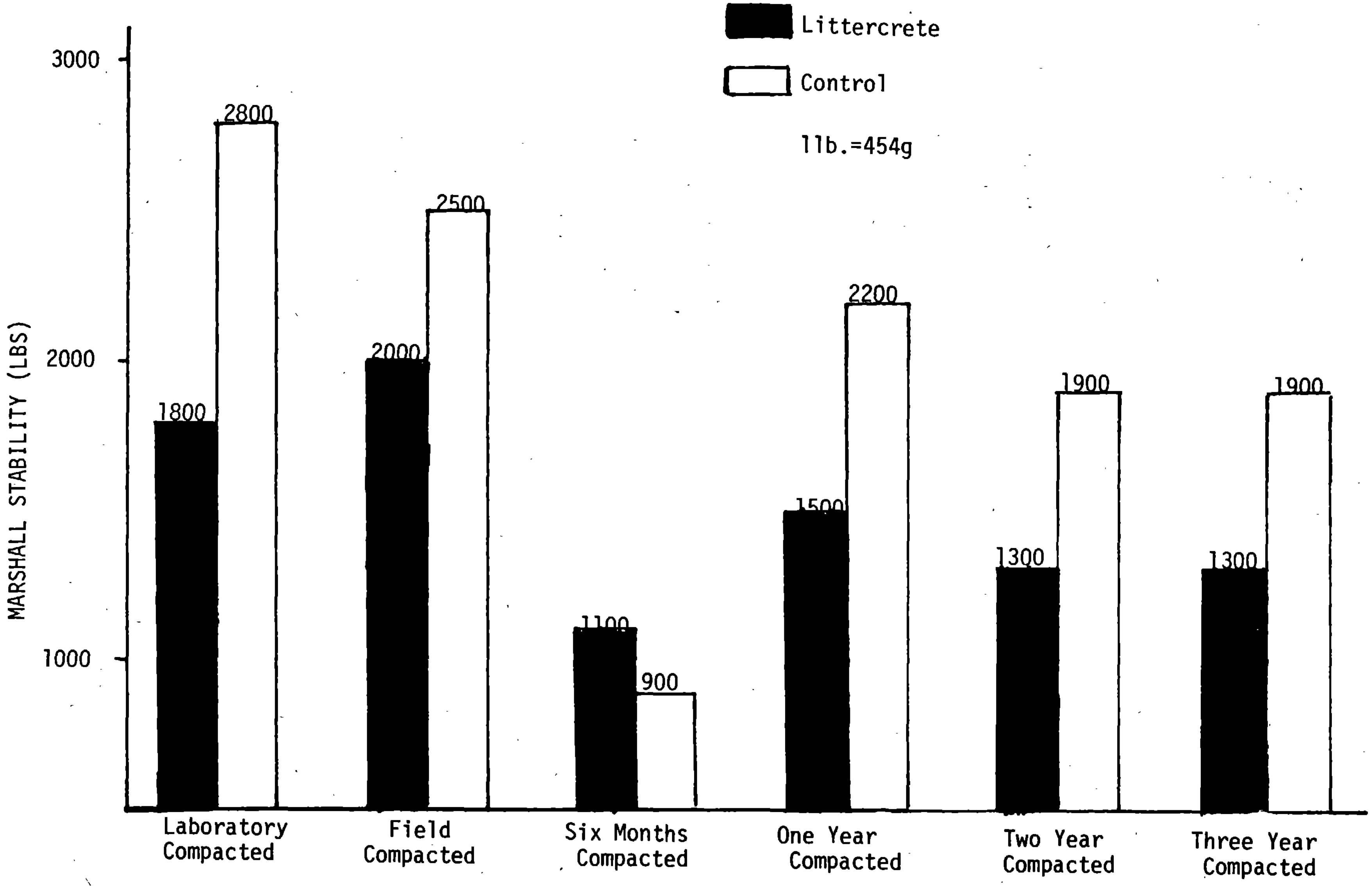


Figure 7 Bar graph showing Marshal Stability values at various times in Service.

stitute of 750 lb (3336N)(13) was easily met by both the littercrete and blackbase control mixes, when placed.

Three year in-service Hveem Stability values for the littercrete were 20 (a 33% reduction) and for the control were 49 (a 5% reduction). With time in service the Marshall stability of the littercrete samples decreased from 1815 to 1349 (a 26% reduction) while the control samples decreased from 2830 to 1940 (a 31% reduction). The meaning of these reductions is not clear. Certainly some reduction in stability is to be expected. The Marshall values are still quite high, exceeding the recommended as-constructed minimum. On the other hand, the Hveem values for the littercrete are somewhat low. The literature yields no clues as to whether or not a reduction in Hveem values indicates future problems with the littercrete.

5.4 Splitting Tensile Strength

Graphs of the ultimate tensile strength of the various samples versus the unit deformation rate can be found in Appendix B for one, two and three year in-service specimens.(9,12) Linear regression lines showing the increase in strength with increasing deformation were determined. Figures 8,9,and 10 show a comparison of the splitting tensile strength results between the littercrete and control sections at 74°F (23°C) for one, two and three years in service. These figures indicate the two mixes have essentially the same ultimate splitting tensile strength for all three ages, which means the littercrete is holding up essentially the same as the black base control section in terms of load carry capacity.

5.5 Schmidt Test

Resilient Modulus versus temperature relationships are shown in Figures 11, 12, and 13.(9) The data for these graphs along with the 90% confidence limits of the specimens can be found in Appendix C of this report. The one, two, and three year field compacted samples were compared to resilient modulus at time of construction. In these figures it can be seen that the aged samples tend to have slightly greater values of resilient modulus. This would be expected taking time and traffic into consideration. After three years in service (Figure 11) the littercrete is performing essentially the same as when it was placed, while the control section has somewhat "hardened".

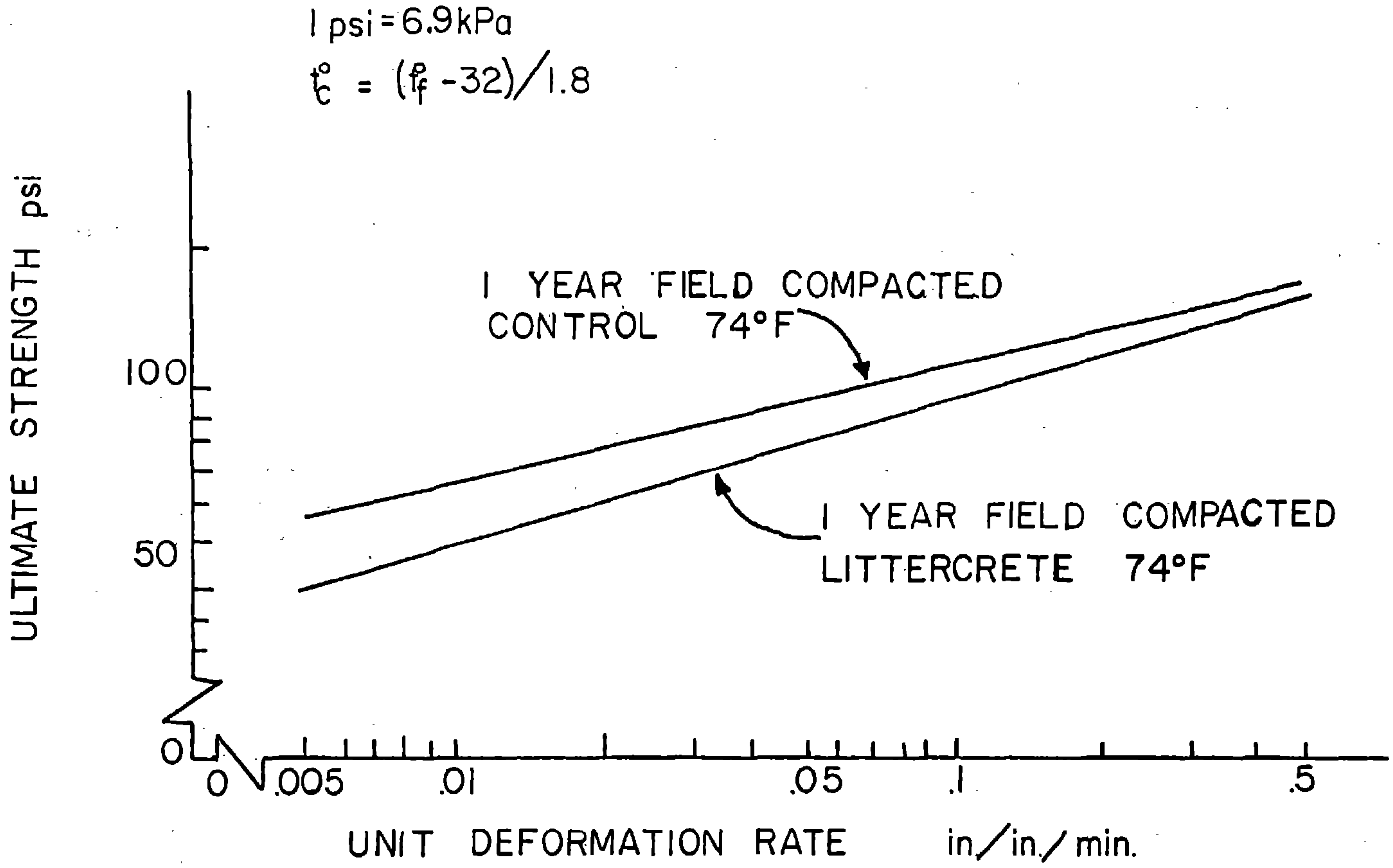


Figure 8 Ultimate strength versus unit deformation rate - 74°F one year field compacted littercrete and control sections splitting tensile test.

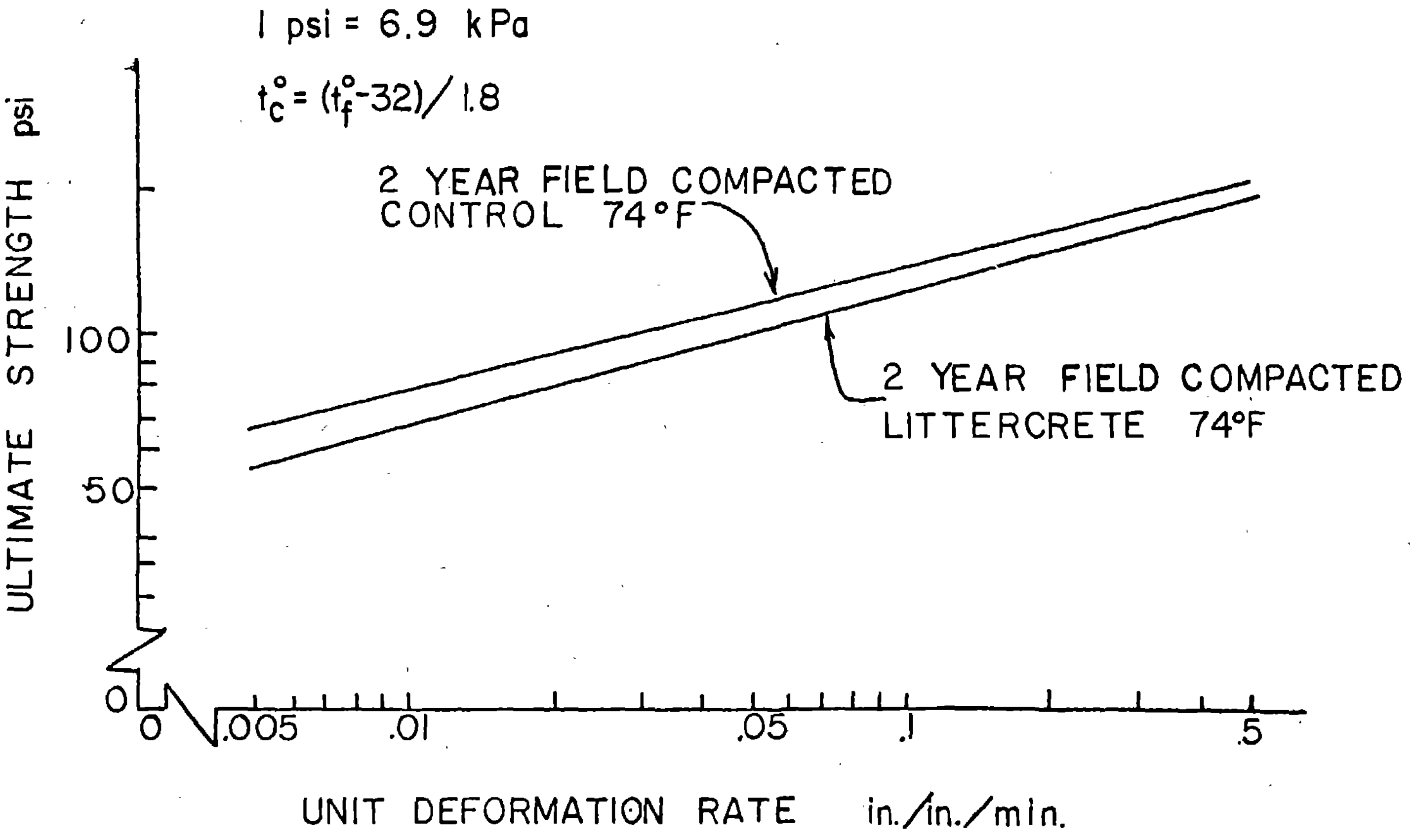


Figure 9 Ultimate strength versus unit defromation rate - 74°F two year field compacted littercrete and control sections splitting tensile test.

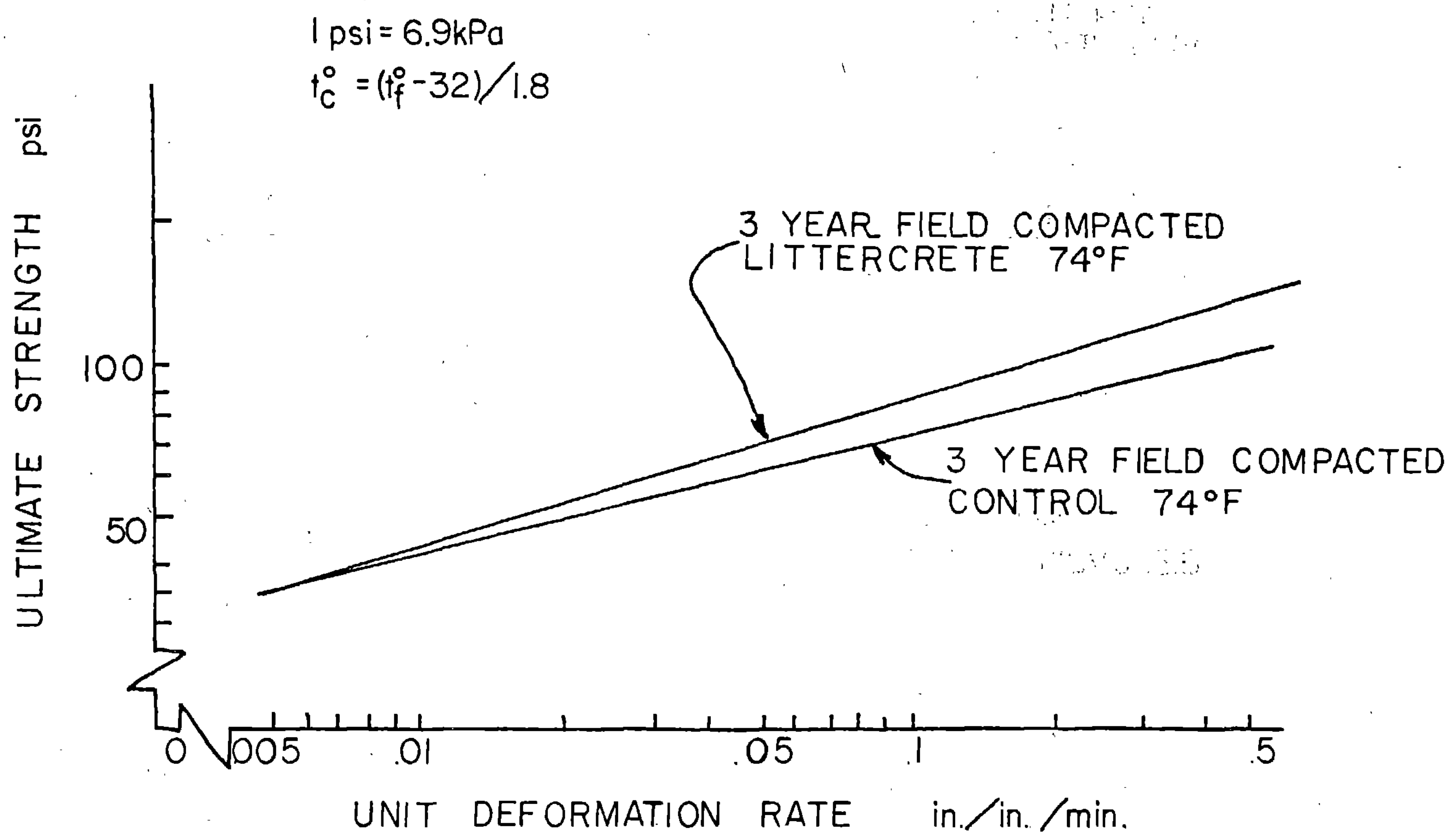


Figure 10 Ultimate strength versus unit deformation rate - 74°F three year field compacted littercrete and control section splitting tensile test.

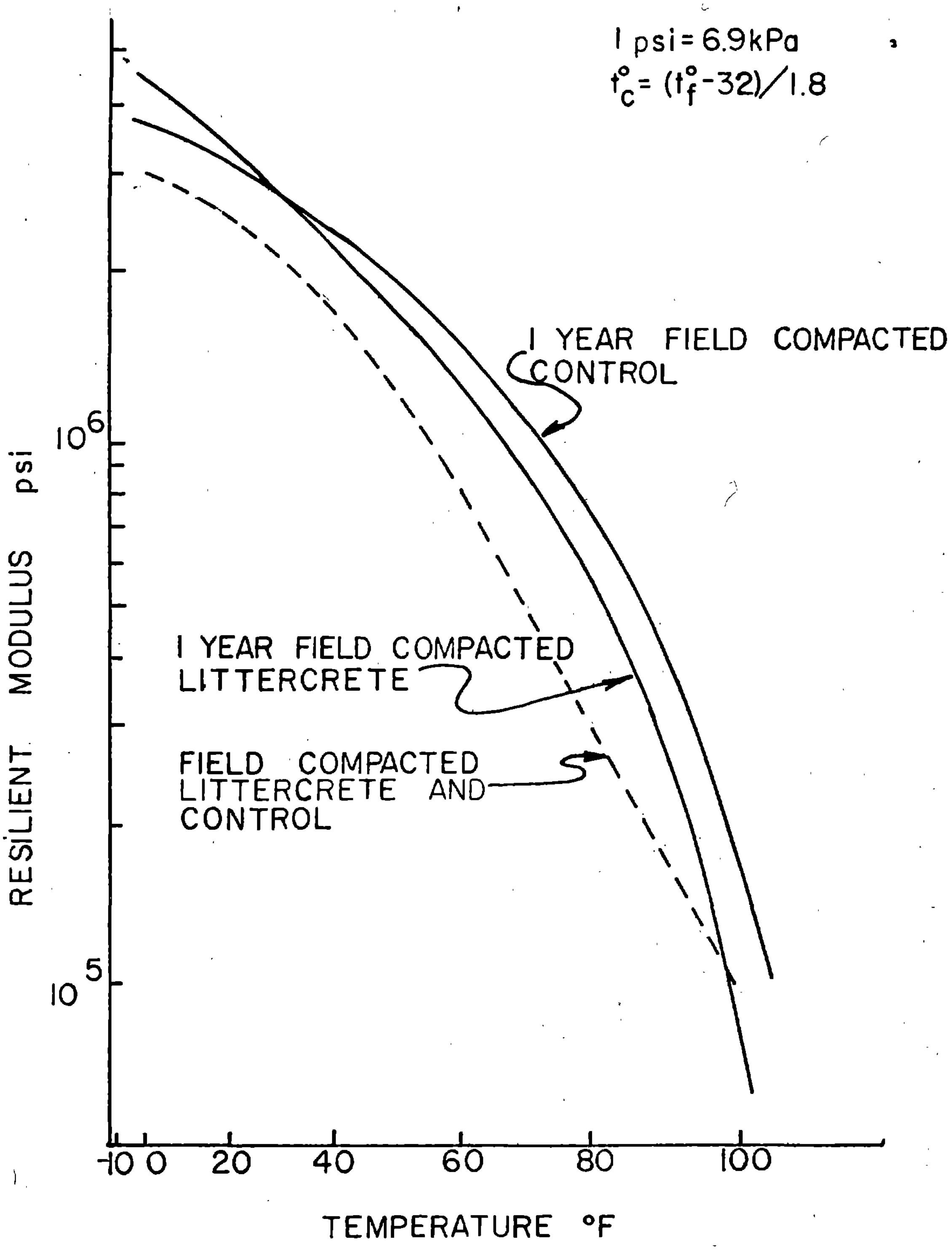


Figure 11 Resilient Modulus versus temperature field compacted and one year field compacted samples, Schmidt test.

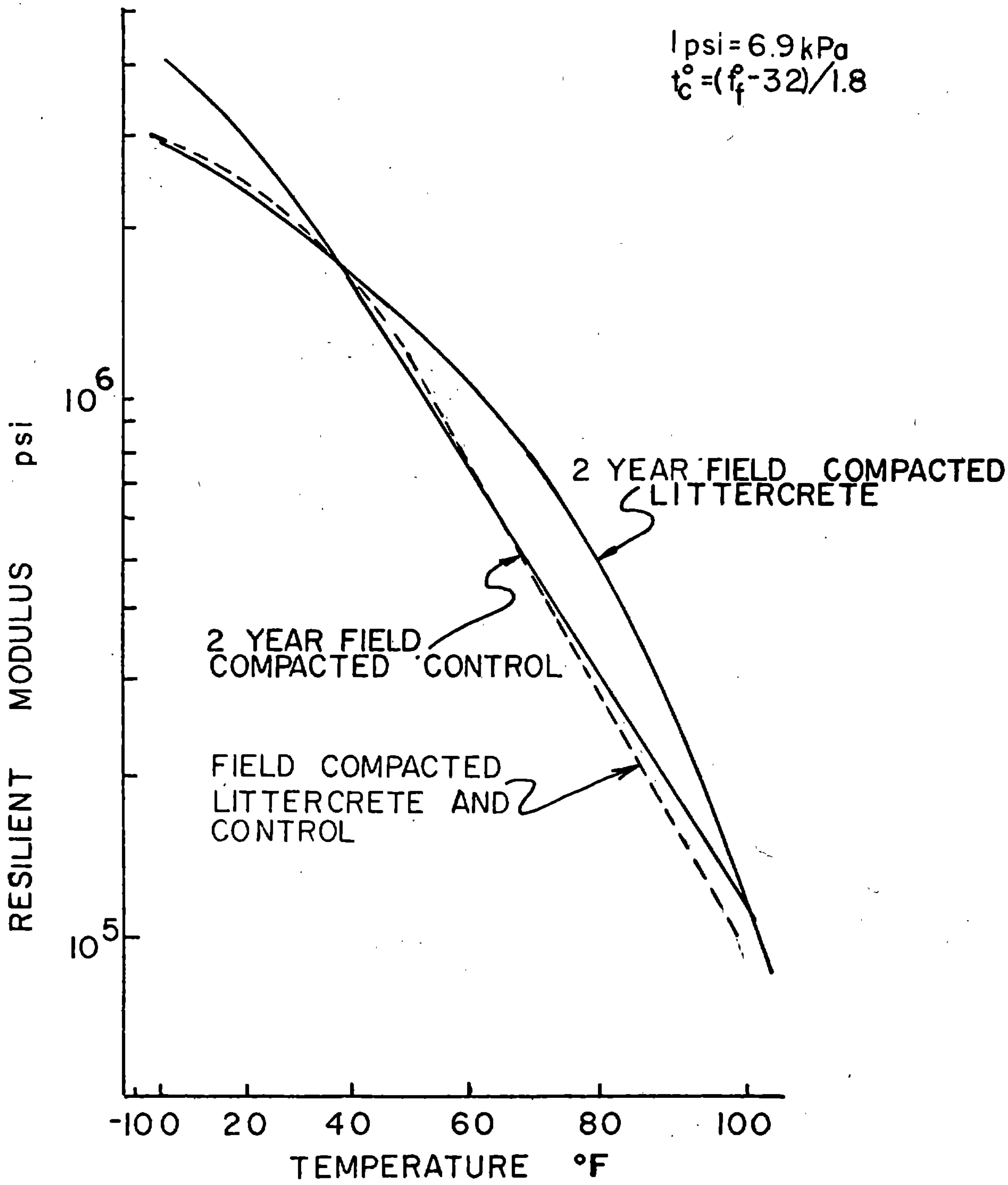


Figure 12 Resilient Modulus versus temperature field compacted and two year field compacted samples, Schmidt test.

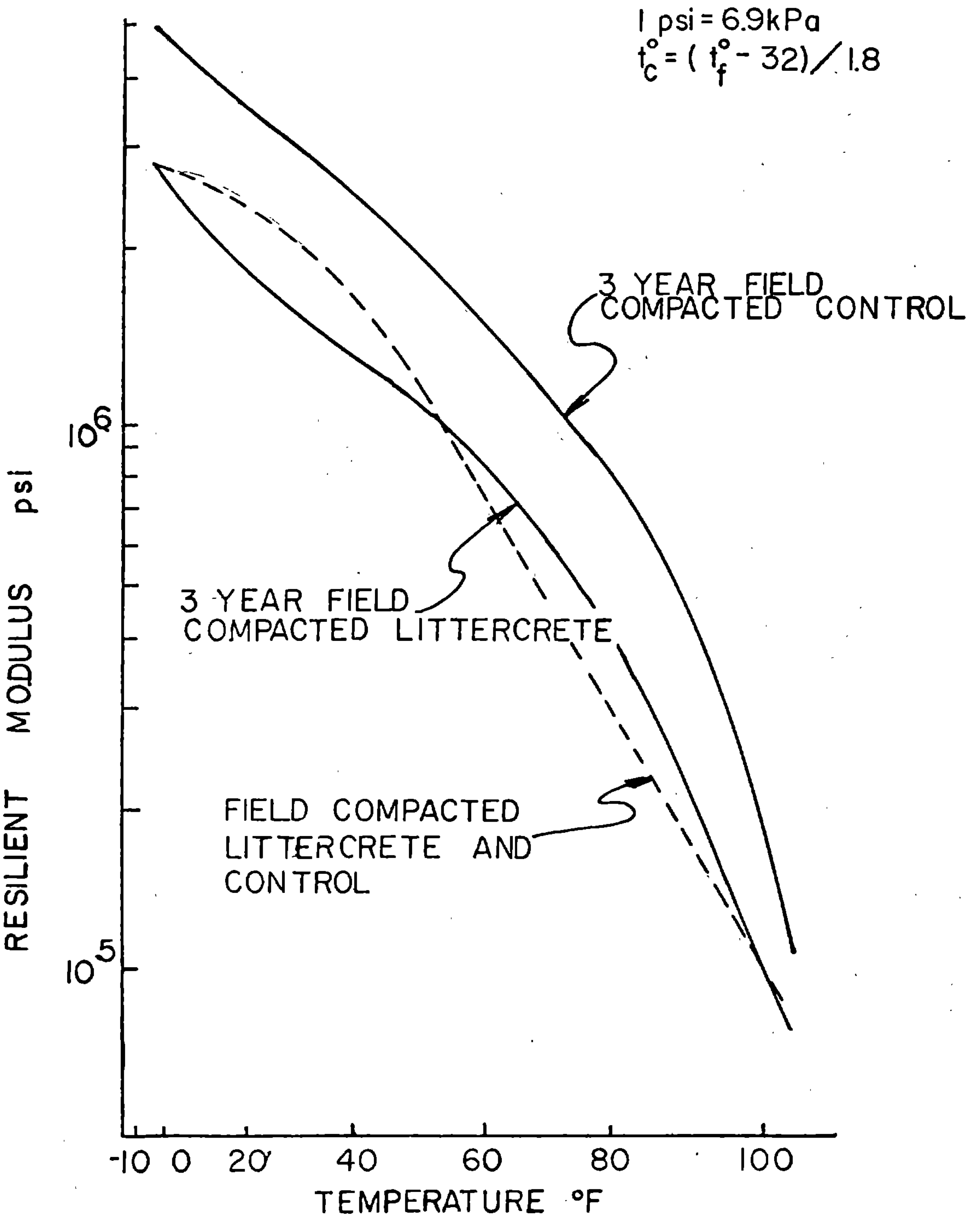


Figure 13 Resilient Modulus versus temperature field compacted and three year field compacted samples, Schmidt test.

6. Implications of Results

As expected, some conflicting results were obtained. The Hveem stability values for the littercrete dropped significantly with time. What this means is not clear at present. Marshall Stability values are still quite good. Splitting tensile strengths and Resilient Modulus look excellent. And of course visual examinations indicate that the littercrete section is performing essentially the same as the blackbase control section. So the prognosis looks good. After three years in service all signs point to a long healthy life for the littercrete.

APPENDIX A - EXPERIMENTAL RESULTS SUMMARY

Table 4 Experimental Results Summary for Stability Tests.

Material	Number of Samples	Stability Value	90% Confidence Limits for Hveem Stabilometer Values	Percent Air Voids	Flow in.
(a) Hveem Stability[a]					
Laboratory compacted Littercrete	6	30	2.78	2.5	--
Field compacted Littercrete	3	34	5.46	3.6	--
Six months Field compacted Littercrete	3	24	6.19	4.2	--
Laboratory compacted Control	3	52	11.92	9.8	--
Field compacted Control	3	48	5.20	7.5	--
Six months Field compacted Control	3	56	7.44	8.5	--

Table 4. Experimental Results Summary for Stability Tests. (Continued)

Material	Number of Samples	Stability Value	90% Confidence Limits for Hveem Stabilometer Values	Percent Air Voids	Flow in.
(a) Hveem Stability[a]					
One Year Field Compacted Littercrete	4	19.	3.5	5.4	-
Two Year Field Compacted Littercrete	3	17.	2.1	8.4	-
Three Year Field Compacted Littercrete	3	20.	4.4	4.7	
One Year Field Compacted Control	3	42.	4.5	5.4	-
Two Year Field Compacted Control	3	35.	9.2	4.6	-
Three Year Field Compacted Control	3	49.	5.2	6.9	-

[a] ASTM Designation D1560

[b] ASTM Designation D1559

1 lb = 454g

1 in. = 2.54 cm

Table 4 Experimental Results Summary for Stability Tests. (Continued)

Material	Number of Samples	Stability Value	90% Confidence Limits for Marshall Stability Values	Percent Air Voids	Flow in.
(b) Marshall Stability[b] (lb)					
Laboratory compacted Littercrete	6	1815	215.65	2.4	.19
Field compacted Littercrete	3	1970	1132.67	3.6	.11
Six months Field compacted Littercrete	3	1150	578.25	4.2	.17
Laboratory compacted Control	3	2830	661.69	9.8	.14
Field compacted Control	3	2510	1030.79	7.5	.16
Six months Field compacted Control	3	920	862.96	8.5	.15

[a] ASTM Designation D1560. 1 lb = 454 g

[b] ASTM Designation D1559. 1 in. = 2.54 cm

Table 4 Experimental Results Summary for Stability Tests. (Continued)

Material	Number of Samples	Stability Value	90% Confidence Limits for Marshall Stability Values	Percent Air Voids	Flow in.
(b) Marshall Stability[b] (lb)					
One Year Field Compacted Littercrete	6	1500	111.	4.9	.16
Two Year Field Compacted Littercrete	3	134	245.	7.4	.17
Three Year Field Compacted Littercrete	2	134	20.	4.7	.18
One Year Field Compacted Control	3	220	539.	5.4	.13
Two Year Field Compacted Control	3	192	17.	4.2	.12
Three Year Field Compacted Control	3	1940	382.	6.9	.12

[a] ASTM Designation D1560.

[b] ASTM Designation D1559

1 lb = 454 g

1 in. = 2.54 cm

Table 5 Stability Tests Results. (Control)

Specimen Number	Bulk Specific Gravity	Air Voids Percent	Hveem Stabilometer Reading	Marshall Stability lbs	Marshall Flow in.
One Year Field Compacted Control					
C1A	2.283	3.3	42.0	2000	.09
C1B	2.195	7.1	47.0	2900	.11
C6C	2.225	5.8	37.5	1850	.18
Two Year Field Compacted Control					
C10C	2.281	4.2	31.0	1911	.13
C18A	2.271	4.6	46.0	1946	.12
C15B	2.291	3.7	28.2	1918	.12
Three Year Field Compacted Control					
C12A	2.254	7.4	48.0	2020	.12
C14B	2.270	6.8	55.0	1837	.09
C16C	2.272	6.7	44.0	1465	.14

1 lb = 454 g
1 in. = 254 cm

Table 6 Stability Tests Results. (Littercrete)

Specimen Number	Bulk Specific Gravity	Air Voids Percent	Hveem Stabilometer Reading	Marshall Stability lbs	Marshall Flow in.
One Year Field Compacted Littercrete					
L10A	2.086	4.3	14.5	1550	.15
L12B	2.040	2.4	17	1330	.18
L11C	-	-	-	1300	.18
T9A	2.081	4.1	-	1675	.11
T17B	2.015	3.6	24.5	1650	.14
T18C	2.060	3.8	20.5	1525	.17
Two Year Field Compacted Littercrete					
L3A	1.954	8.6	17	1396	.19
L5C	1.963	8.3	20	1411	.16
L7B	2.024	5.2	15	1220	.16

1 lb = 454g
1 in. = 2.54 cm

Table 6 Stability Tests Results. (Continued)

Specimen Number	Bulk Specific Gravity	Air Voids Percent	Hveem Stabilometer Reading	Marshall Stability lbs	Marshall Flow in.
Three Year Field Compacted Littercrete					
L1C	2.048	3.9	16	-	-
L5A	2.025	5.0	18	1463	.19
L5B	2.016	5.4	25	1235	.18

1 lb = 454 g
1 in. = 2.54 cm

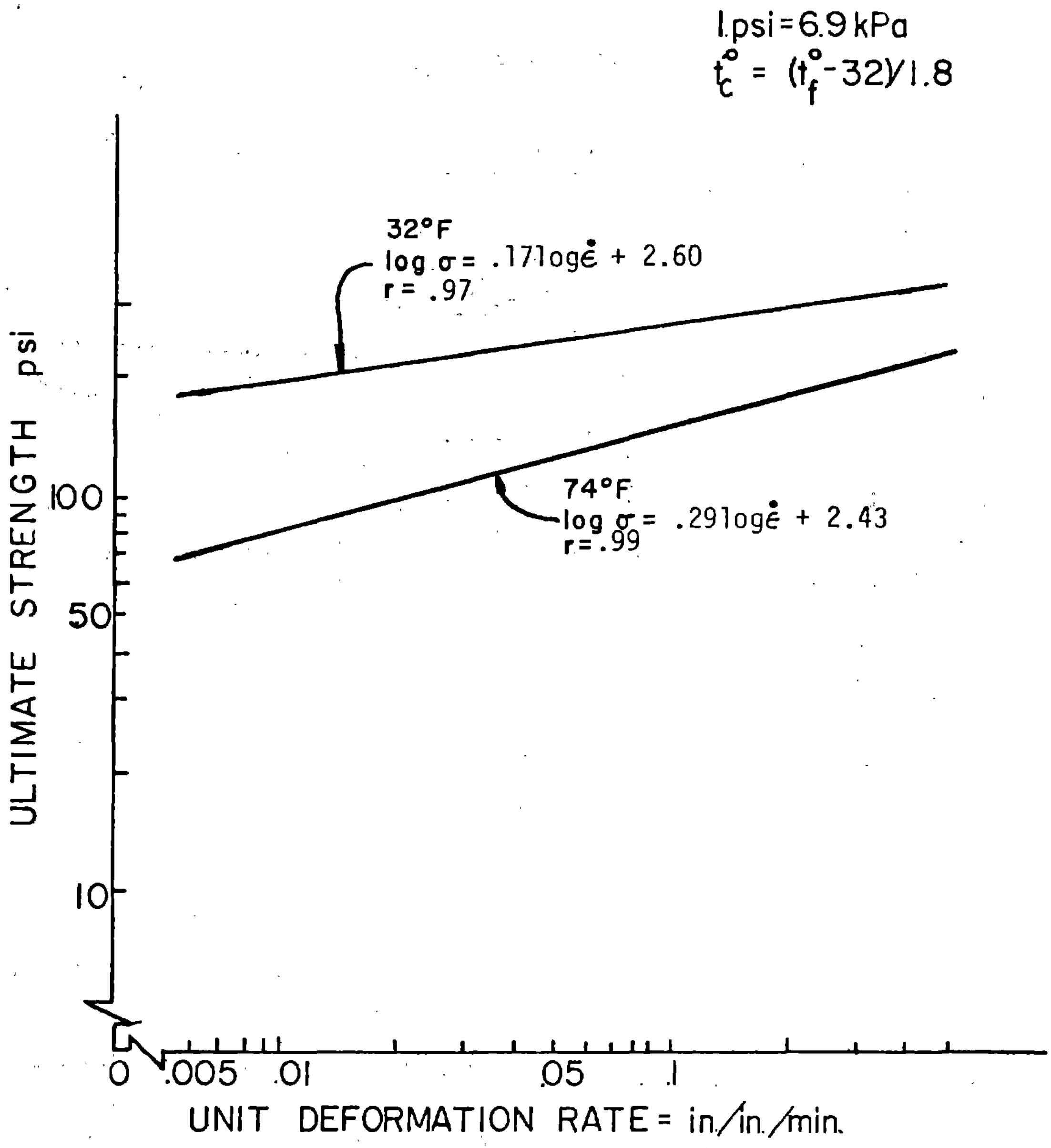


Figure 14 Ultimate strength versus unit deformation rate one year field compacted control splitting tensile test

1 psi = 6.9 kPa
$t_c^{\circ} = (t_f^{\circ} - 32)/1.8$

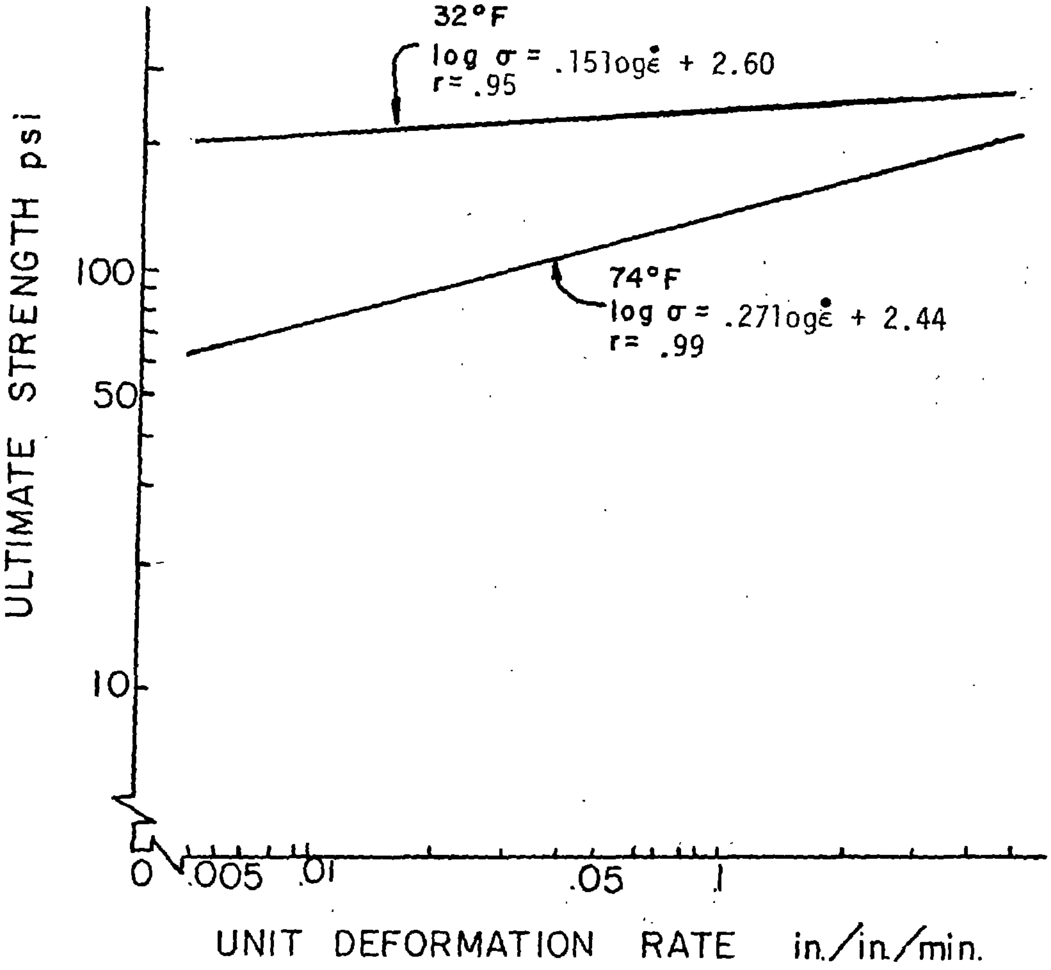


Figure 15 Ultimate strength versus unit deformation rate two year field compacted control splitting tensile test.

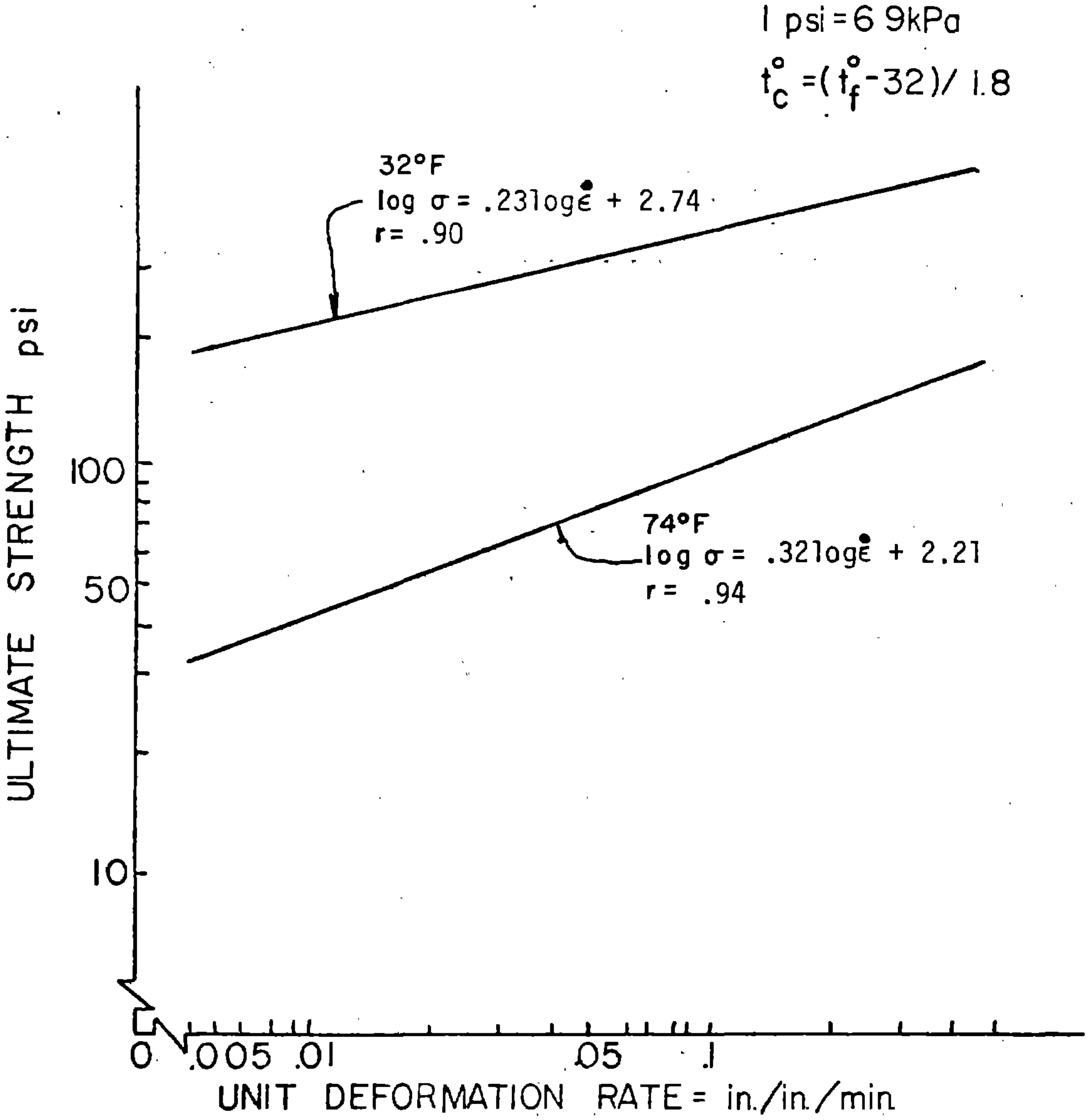


Figure 16 Ultimate strength versus unit deformation rate three year field compacted control splitting tensile test.

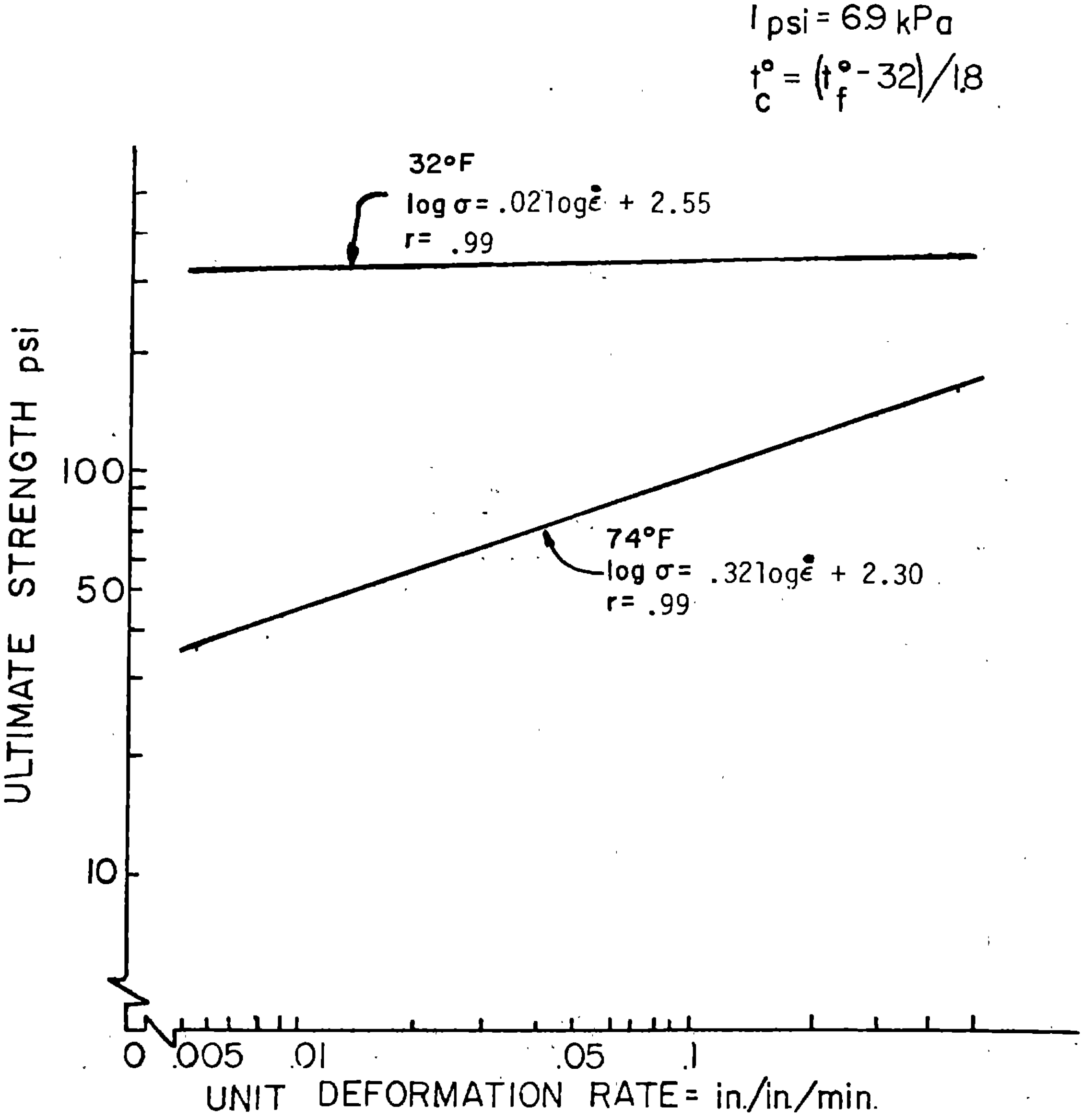


Figure 17 Ultimate strength versus unit deformation rate one year field compacted littercrete splitting tensile test.

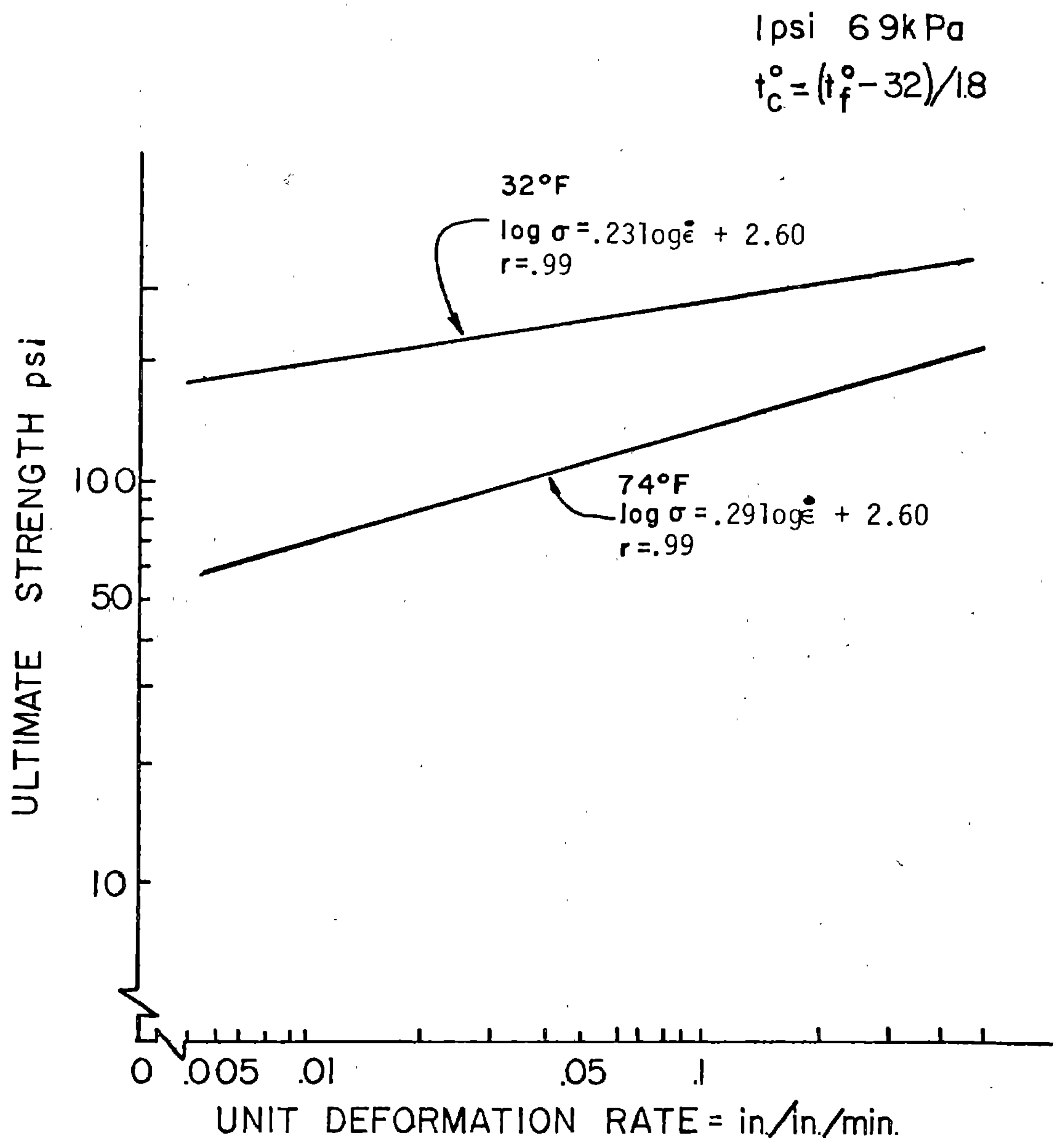


Figure 18 Ultimate strength versus unit deformation rate-two year field compacted littercrete splitting tensile test.

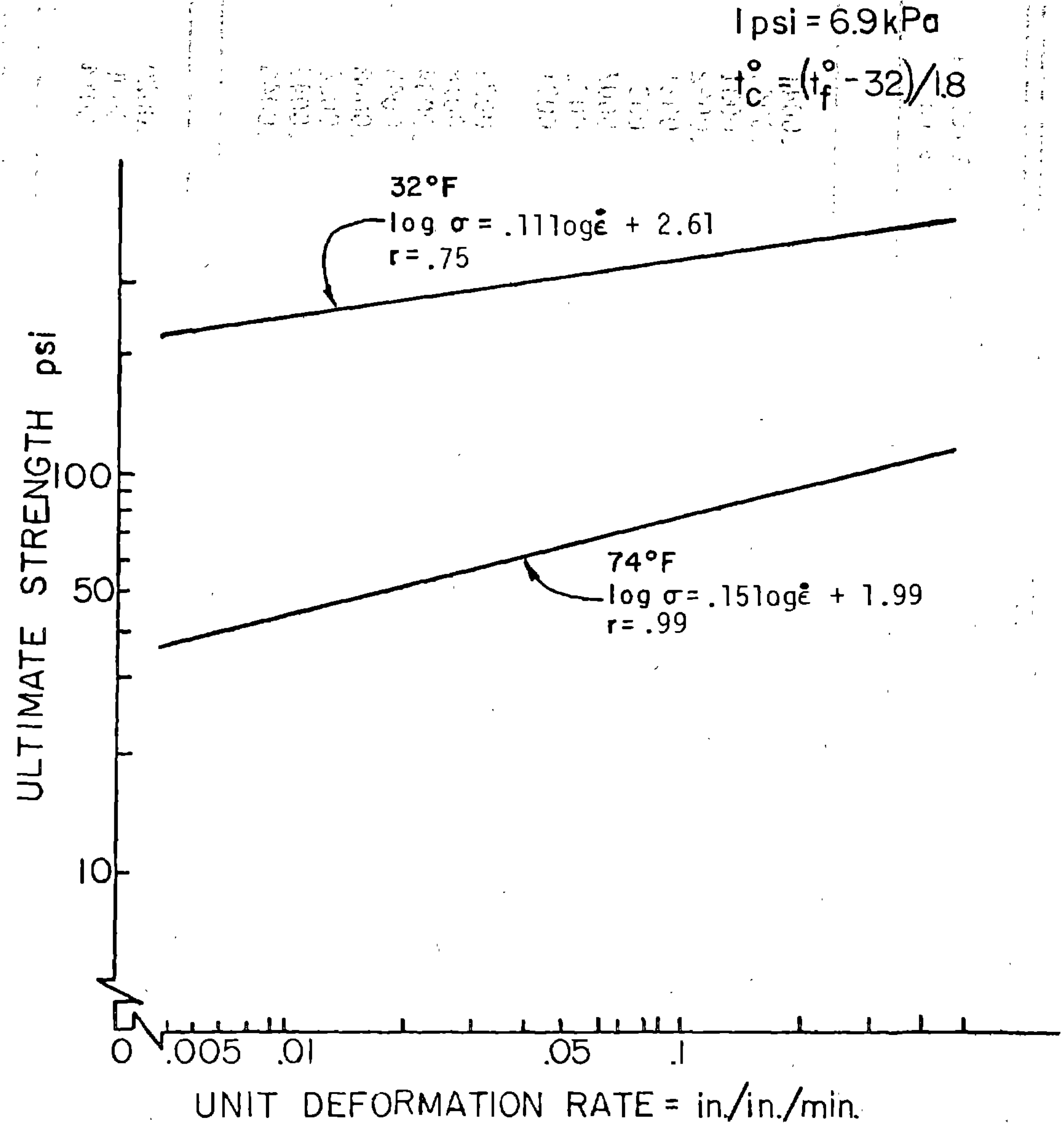


Figure 19 Ultimate strength versus unit deformation rate three year field compacted littercrete splitting tensile test.

Table 7 Splitting Tensile Test Data (Littercrete).

Sample Number	Percent Air Voids	Temperature °F	Deformation Rate in/in/min	Ultimate Strength psi	Failure Strain	Modulus ksi
One Year Field Compacted Littercrete						
11A	1.5	33	.005	326	.0041	173
12C	1.6	33	.005	312	.0044	157
10B	3.3	33	.005	318	.0031	222
12A	3.6	33	.05	282	.0022	280
11B	4.2	33	.05	404	.0031	282
16C	5.2	33	.05	302	.0009	762
15C	4.4	33	.5	400	.0007	1200
14B	5.2	33	.5	364	.0021	386
13A	5.9	33	.5	265	.0021	281
14A	4.3	74	.005			
13B	5.6	74	.005	38	.0023	68
10C	3.3	74	.005	35	.0018	96
15A	1.7	74	.05	88	.0034	152
16B	3.2	74	.05	78	.0045	134
14C	4.2	74	.05	69	.0068	117
13C	2.7	74	.5	158	.0038	226
15B	1.2	74	.5	154	.0045	296
16A	4.4	74	.5	166	.0040	472
Two Year Field Compacted Littercrete						
L8A	6.7	33	.005	172	.0020	714
L9B	6.7	33	.005	174	.0005	2980
L4C	6.4	33	.005	182	.0014	1074

$t_C = (t_F - 32) / 1.8$ 1 in. = 2.54 cm 1 psi = 6.9 kPa

Table 7 Splitting Tensile Test Data (Littercrete).(Continued)

Sample Number	Percent Air Voids	Temperature °F	Deformation Rate in/in/min	Ultimate Strength psi	Failure Strain	Modulus ksi
Two Year Field Compacted Littercrete (Continued)						
L6B	5.0	33	.05	354	.0017	1747
L3B	12.8	33	.05	193	.0013	1217
L7A	5.3	33	.05	423	.0018	2011
L6C	6.0	33	.5	173	.0024	698
L4B	6.0	33	.5	164	.0015	998
L2A	6.7	33	.5	398	.0019	1763
L5A	6.4	74	.005	64	.0048	111
L2B	6.7	74	.005	50	.0053	80
L7C	5.4	74	.005	49	.0057	73
L8C	5.4	74	.05	119	.0041	240
L9A	6.0	74	.05	109	.0094	200
L5B	6.1	74	.05	93	.0058	133
L1B	5.0	74	.5	215	.0031	577
L6A	4.5	74	.5	240	.0035	567
L8B	6.7	74	.5	198	.0033	493
L4A	8.6	74	.5	194	.0024	670

$t\,^0C = (t\,^0F - 32)/1.8$ 1 in. = 2.54 cm 1 psi = 6.9 kPa

Table 7 Splitting Tensile Test Data (Littercrete). (Continued)

Sample Number	Percent Air Voids	Temperature °F	Deformation Rate in/in/min	Ultimate Strength psi	Failure Strain	Modulus ksi
THREE YEAR FIELD COMPACTED LITTERCRETE						
L10B	5.1	32	.005	222	.0011	193
L1A	5.5	32	.005	182	.0016	115
L3A	3.7	32	.05	373	.0008	438
L11A	4.2	32	.05	382	.0010	400
L11B	5.1	32	.5	358	.0028	127
L12A	5.6	32	.5	277	.0022	124
L7B	1.4	32	.5	316	.0033	96
L6B	6.6	32	.5	403	.0038	106
L12B	8.7	74	.005	32	.0044	73
L1B	6.6	74	.05	58	.0069	83
L8A	5.7	74	.05	63	.0040	158
L4A	4.6	74	.05	91	.0058	156
L8B	4.9	74	.5	109	.0052	209
L10A	5.1	74	.5	107	.0055	194
L3B	6.4	74	.5	89	.0037	240

$t^0c = (t^0F - 32)/1.8$ 1 in. = 2.54 cm 1 psi = 6.9 kPa

Table 8 Splitting Tensile Test Summary (Littercrete).

Sample	Number of Specimens	Temperature °F	Deformation Rate in/in/min	Ultimate Tensile Strength psi	Failure Strain	Modulus ksi
One Year Field Compacted Littercrete						
	3	33	.005	318	.0038	182
			.05	329	.0021	441
			.5	343	.0016	622
	2	74	.005	36	.0020	82
	3		.05	78	.0049	161
			.5	158	.0041	331
Two Year Field Compacted Littercrete						
	3	33	.005	176	.0013	1589
			.05	323	.0016	1658
			.5	245	.0019	1153
	3	74	.005	55	.0052	88
	3		.05	106	.0065	191
	4		.5	211	.0030	576

$t^0c = (t^0F - 32)/1.8$ 1 in. = 2.54 cm 1 psi = 6.9 kPa

Table 8. Splitting Tensile Test Summary (Littercrete). (Continued)

Sample Number	Number of Samples	Temperature °F	Deformation Rate in/in/min	Ultimate Strength psi	Failure Strain	Modulus ksi
Three Year Field Compacted Littercrete						
	2	32	.005	202	.0014	154
	2	32	.05	378	.0009	419
	4	32	.5	338	.0030	113
	1	74	.005	32	.0044	73
	3	74	.05	71	.0055	132
	3	74	.5	101	.0047	214

t c = (t F - 32)/1.8 1 in. = 2.54 cm 1 psi = 6.9 kPa

Table 9 Splitting Tensile Test Data (Control)

Sample Number	Percent Air Voids	Temperature °F	Deformation Rate in/in/min	Ultimate Strength psi	Failure Strain	Modulus ksi
One Year Field Compacted Control						
4C	6.9	33	.005	153	.0011	315
3B	6.2	33	.005	279	.0034	180
2A	3.0	33	.005	312	.0033	213
5C	5.6	33	.05	186	.0065	867
6B	2.8	33	.05	302	.0011	584
7A	3.7	33	.5	263	.0008	1000
5B	3.1	33	.5	390	.0011	739
1C	4.6	33	.5	356	.0014	557
4A	4.1	74	.005	78	.0009	199
7B	2.9	74	.005	67	.0013	166
2C	6.1	74	.005	38	.0011	94
5A	3.9	74	.05	108	.0011	210
4B	2.9	74	.05	110	.0011	225
3C	2.2	74	.05	83	.0012	151
6A	3.4	74	.5	196	.0008	535
8B	2.0	74	.5	122	.0009	285
7C	3.7	74	.5	197	.0009	463
Two Year Field Compacted Control						
C10B	5.7	33	.005	139	.0022	521
C15A	3.6	33	.005	239	.0021	1001
C12C	4.4	33	.005	223	.0016	1016
C14B	6.0	33	.05	260	.0023	950
C16A	3.9	33	.05	412	.0020	1681
C17B	7.0	33	.05	256	.0019	1122
C13A	4.2	33	.5	203	.0024	716
C16B	7.0	33	.5	111	.0012	404
C11C	6.8	33	.5	159	.0028	479

$t_C = (t_F - 32)/1.8$ 1 in. = 2.54 cm 1 psi = 6.9 kPa

Table 9 Splitting Tensile Test Data (Control) (Continued)

Sample Number	Percent Air Voids	Temperature °F	Deformation Rate in/in/min	Ultimate Strength psi	Failure Strain	Modulus ksi
Two Year Field Compacted Control (Continued)						
C13B	5.4	74	.005	59	.0053	95
C11A	4.3	74	.005	71	.0039	152
C10A	4.3	74	.005	67	.0037	153
C17A	5.0	74	.05	108	.0038	237
C11B	5.4	74	.05	140	.0041	238
C12B	5.4	74	.05	119	.0056	178
C18B	3.6	74	.5	173	.0020	721
C12A	4.5	74	.5	253	.0033	645
C14A	4.7	74	.5	243	.0033	623
Three Year Field Compacted Control						
C14A	6.2	32	.005	64	.0012	53
C15C	6.2	32	.005	210	.0028	74
C16C	6.7	32	.05	327	.0036	90
C13A	5.8	32	.05	393	.0013	130
C13B	5.6	32	.5	425	.0033	130
C19B	5.3	32	.5	427	.0033	130
C11A	5.9	32	.5	384	.0022	177
C13C	7.1	74	.005	32	.0052	91
C11B	5.9	74	.05	96	.0036	260
C14C	6.7	74	.05	72	.0022	130
C19C	5.7	74	.5	149	.0034	129
C15C	6.2	74	.5	163	.0032	150
C11C	7.5	74	.5	134	.0055	120

$t\,^{0}C = (t\,^{0}F - 32)/1.8$ 1 in = 2.54 cm 1 psi = 6.9 kPa

Table 10 Splitting Tensile Test Summary (Control)

Sample	Number of Specimens	Temperature °F	Deformation Rate in/in/min	Ultimate Tensile Strength psi	Failure Strain	Modulus ksi
One Year Field Compacted Control						
	3	33	.005	154	.0025	236
	3		.05	256	.0008	740
	3		.5	336	.0011	765
	3	74	.005	61	.0011	153
	3		.05	100	.0011	195
	3		.5	237	.0009	427
Two Year Field Compacted Control						
	3	33	.005	200	.0020	846
	3		.05	309	.0021	1253
	3		.5	158	.0021	533
	3	74	.005	66	.0043	133
	3		.05	122	.0045	218
	3		.5	223	.0029	663

$t\,^0C = (t\,^0F - 32)/1.8$ 1 in. = 2.54 cm 1 psi = 6.9 kPa

Table 10 Splitting Tensile Test Summary (Control) (Continued)

Sample Number	Number of Samples	Temperature °F	Deformation Rate in/in/min	Ultimate Strength psi	Failure Strain	Modulus ksi
Three Year Field						
Compacted Control						
	2	32	.005	137	.0020	64
	2	32	.05	360	.0024	110
	3	32	.5	412	.0029	145
	1	74	.005	32	.0052	91
	2	74	.05	84	.0045	200
	3	74	.5	148	.0040	133

$t^0c = (t^0F - 32)/1.8$ 1 in. = 2.54 cm 1 psi = 6.9 kPa

APPENDIX C - Schmidt Test Results

Table 11 Schmidt Test Results.

Sample Number	Specific Gravity	Percent Air Voids	Temperature ^0F	Resilient Modulus ksi
(A) One Year Field Compacted Control				
C-1A	2.282	3.3	-9	3651
C-1B	2.195	7.1	-9	4303
C-6C	2.225	5.8	-9	3180
C-1A	2.282	3.3	32	2709
C-1B	2.195	7.1	32	2750
C-6C	2.225	5.8	32	1991
C-1A	2.282	3.3	68	1186
C-1B	2.195	7.1	68	920
C-6C	2.225	5.8	68	837
C-1A	2.282	3.3	100	133
C-1B	2.195	7.1	100	120
C-6C	2.225	5.8	100	111

Table 11 Schmidt Test Results. (Continued)

Sample Number	Specific Gravity	Percent Air Voids	Temperature ^0F	Resilient Modulus ksi
(B) One Year Field Compacted Littercrete (Heavy Traffic)				
T9A	2.081	.4	-9	4423
T17B	2.015	3.5	-9	3107
T18C	2.060	1.4	-9	3320
T9A	2.081	0.4	32	2548
T17B	2.015	3.5	32	1948
T18C	2.060	1.4	32	1503
T9A	2.081	0.4	68	943
T17B	2.015	3.5	68	333
T18C	2.060	1.4	68	631
T9A	2.081	0.4	100	74
T17B	2.015	3.5	100	98
T18C	2.060	1.4	100	65
(C) One Year Field Compacted Littercrete (Light traffic)				
L-10A	2.086	.2	-9	4441
L-12B	2.040	2.4	-9	4444
L-10A	2.086	.2	32	2588
L-12B	2.040	2.4	32	2075
L-10A	2.086	.2	68	814
L-12B	2.040	2.4	68	842
L-10A	2.086	.2	100	058
L-12B	2.040	2.4	100	059

Table 11 Schmidt Test Results. (Continued)

Sample Number	Specific Gravity	Percent Air Voids	Temperature °F	Resilient Modulus ksi
(D) Two Year Field Compacted Control				
C10C	2.281	4.2	-9	4388
C18A	2.271	4.6	-9	6331
C15B	2.291	3.7	-9	5089
C10C	2.281	4.2	32	1801
C18A	2.271	4.6	32	2050
C15B	2.291	3.7	32	2189
C10A	2.280	4.2	74	471
C10B	2.246	5.6	74	434
C10C	2.281	4.2	74	404
C11A	2.271	4.2	74	482
C11B	2.291	5.1	74	577
C11C	2.281	6.6	74	500
C12A	2.276	4.3	74	563
C12B	2.254	5.3	74	459
C12C	2.278	4.3	74	478
C13A	2.284	4.0	74	490
C13B	2.251	5.4	74	468
C14A	2.272	4.5	74	514
C14B	2.242	5.7	74	495
C15A	2.298	3.4	74	500
C15B	2.291	3.7	74	417
C16A	2.290	3.7	74	520
C16B	2.215	6.9	74	353

Table 11 Schmidt Test Results. (Continued)

Sample Number	Specific Gravity	Percent Air Voids	Temperature °F	Resilient Modulus ksi
C17A	2.266	4.8	74	456
C17B	2.306	3.1	74	407
C18A	2.271	4.6	74	450
C18B	2.298	3.4	74	558
C10C	2.281	4.2	104	92
C18A	2.271	4.6	104	173
C15 B	2.291	3.7	104	90
(E) Two Year Field Compacted Littercrete				
L3A	1.954	8.6	-9	3318
L5C	1.963	8.3	-9	2381
L7B	2.025	5.2	-9	3560
L3A	1.954	8.6	32	1712
L5C	1.963	8.3	32	1903
L7B	2.025	5.2	32	1808
L1A	1.993	6.8	74	644
L1B	2.032	5.0	74	549
L2A	1.995	6.7	74	625
L2B	1.995	6.7	74	548
L3A	1.954	8.6	74	564
L3B	1.866	12.8	74	410
L4A	1.954	8.7	74	663
L4B	2.012	6.0	74	440
L4C	2.003	6.4	74	552

Table 11 Schmidt Test Results. (Continued)

Sample Number	Specific Gravity	Percent Air Voids	Temperature ^{0}F	Resilient Modulus ksi
L5A	2.003	6.4	74	698
L5B	2.010	6.1	74	475
L5C	1.963	8.3	74	494
L6A	2.037	4.8	74	669
L6B	2.033	5.0	74	509
L7A	2.027	5.3	74	608
L7B	2.025	5.2	74	288
L7C	2.024	5.4	74	475
L8A	1.997	6.7	74	436
L8B	1.995	6.0	74	619
L8C	2.030	5.0	74	575
L9A	2.012	6.0	74	593
L9B	2.015	5.8	74	397
L3A	1.954	8.6	104	1075
L5C	1.963	8.3	104	085
L7B	2.025	5.2	104	036
(F) Three Year Field Compacted Littercrete				
L1C	2.048	3.9	-9	3718
L5A	2.025	5.0	-9	3229
L5B	2.016	5.4	-9	2658
L1C	2.048	3.7	32	1544
L5A	2.025	5.0	32	1559
L5B	2.016	5.4	32	1604

Table 11 Schmidt Test Results. (Continued)

Sample Number	Specific Gravity	Percent Air Voids	Temperature °F	Resilient Modulus ksi
L1A	2.014	5.5	74	485
L1B	1.990	6.6	74	547
L1C	2.048	3.9	74	456
L3A	2.052	3.7	74	484
L3B	1.966	6.4	74	498
L4A	2.034	4.6	74	389
L4B	2.020	5.2	74	418
L5A	2.025	5.0	74	540
L5B	2.016	5.4	74	514
L6A	2.025	5.1	74	512
L6B	1.992	6.6	74	559
L6C	2.053	3.7	74	558
L7A	2.053	5.7	74	482
L7B	2.101	1.4	74	556
L7C	2.041	4.3	74	460
L8A	2.009	5.7	74	505
L8B	2.027	4.9	74	449
L10A	2.024	5.1	74	532
L10B	2.070	2.9	74	518
L11A	2.042	4.2	74	485
L11B	2.023	5.1	74	497
L12A	2.012	5.6	74	557
L12B	1.924	9.7	74	529
L1C	2.048	3.7	100	39

Table 11 Schmidt Test Results. (Continued)

Sample Number	Specific Gravity	Percent Air Voids	Temperature °F	Resilient Modulus ksi
L5A	2.025	5.0	100	46
L5B	2.016	5.4	100	49
(G) Three Year Field Compacted Control				
C12A	2.254	7.4	-9	5703
C14B	2.270	6.8	-9	4627
C16C	2.272	6.7	-9	4495
C12A	2.254	7.4	32	2539
C14B	2.270	6.8	32	2718
C16C	2.272	6.7	32	2951
C11A	2.290	5.9	74	935
C11B	2.292	5.9	74	963
C11C	2.252	7.5	74	925
C12A	2.254	7.4	74	956
C12C	2.22	8.7	74	1053
C13A	2.293	5.8	74	964
C13B	2.298	5.6	74	1009
C13C	2.263	7.1	74	909
C14A	2.283	6.2	74	929
C14B	2.270	6.8	74	1070
C14C	2.272	6.7	74	1059
C15A	2.289	6.0	74	993
C15C	2.285	6.2	74	991
C16A	2.305	5.3	74	896

Table 11 Schmidt Test Results. (Continued)

Sample Number	Specific Gravity	Percent Air Voids	Temperature °F	Resilient Modulus ksi
C16C	2.272	6.7	74	929
C19A	2.306	6.0	74	1077
C19C	2.296	5.7	74	1036
C12A	2.254	7.4	100	127
C14B	2.270	6.2	100	104
C16C	2.272	6.7	100	111

t °c = (t °F - 32)/1.8

1 psi = 6.9 kPa

Table 12 Schmidt Data Summary.

Sample	Number of Samples	Temperature °F	M_R ksi	90% Confidence Limits for M_R	M_R Range ksi
One Year field Compacted Control					
	3	-9	3710	536	3180 - 4803
	3	32	2480	405	1991 - 2750
	3	68	981	173	837 - 1186
	3	100	121	10	111 - 133
One Year field Compacted Littercrete					
	2	-9	4441	—	4441 - 4441
	2	32	2696	424	2588 - 2805
	2	68	828	23	814 - 842
(Light Traffic)	2	100	58	1	58 - 59
One Year field Compacted Littercrete					
	3	-9	3620	671	3107 - 4423
	3	32	2000	498	1503 - 2548
	3	68	800	289	631 - 943
(Heavy Traffic)	3	100	79	16	65 - 98

t°c = (t°F - 32) /1.8

1 psi = 6.9 kPa

Table 12 Schmidt Data Summary (Continued)

Sample	Number of Samples	Temperature °F	M_R ksi	90% Confidence Limits for M_R	M_R Range ksi
Two Year Field Compacted Littercrete					
	3	-9	3086	59	2381 - 3506
	3	32	1807	90	1712 - 1903
	23	74	610	35	389 - 698
	3	104	76	34	36 - 107
Two Year Field Compacted Control					
	3	-9	5089	934	4388 - 6331
	3	32	2065	148	2050 - 208
	23	74	478	20	353 - 577
	3	104	118	45	90 - 173

t°c = (t°F - 32) /1.8

1 psi = 6.9 kPa

Table 12 Schmidt Data Summary (Continued)

Sample	Number of Samples	Temperature °F	M_R ksi	90% Confidence Limits for M_R	M_R Range ksi
Three Year Field Compacted Littercrete					
	3	-9	3201	504	2658 - 3718
	3	32	1569	30	1544 - 1604
	23	74	501	15	389 - 559
	3	109	45	5	39 - 49
Three Year Field Compacted Control					
	3	-9	4942	630	4495 - 5703
	3	32	2736	196	2539 - 2951
	18	74	999	28	897 - 1179
	3	100	114	11	104 - 127

t°c = (t°F - 32) /1.8

1 psi = 6.9 kPa

REFERENCES

1. Professional Engineering Staff, "Can the U. S. Hang in There in Terms of Material Resources?" Professional Engineer, Vol. 43, No. 6, June 1975, pp15-17.

2. Witczak, M. W. "A Generalized Investigation of Selected Highway Design and Construction Factors, by Regional Geomorphic Units within the Continential United States," Research Report NCHRP 1-3(1), Purdue University, 1970.

3. MacFarland, W. F., "Case Study - Houston, Texas," Section 2.2, in Final Report on the Feasibility of Using Solid Waste in Highway Construction and Maintenance, Texas Transportation Institute, Texas A&M University, College Station, Texas, October 1971, p. 23

4. Darney, A. and Franklin, W. E., "Salvage Markets for Materials in Solid Wastes," Environmental Protection Publication (SW-29), Midwest Research Institute, Kansas City, Missouri, 1972, pp 121-124.

5. Environmental Protection Agency, "Second Report to Congress, Resource Reduction," Environmental Protection Publication (SW-122) U. S. Governmental Printing Office, Washington, D. C., 1974.

6. Klumb, David L., and Wendling, R. P., "Electricity from Solid Waste - Union Electric Company's 8000 ton per Day Solid Waste Utilization System," presented at the November, 1975, Annual Meeting of ASCE, Denver, Colorado, p. 12.

7. Kenahan, C. B. et al., "Composition and Characteristics of Municipal Incinerator Residues," A Report of the U. S. Bureau of Mines, U. S. Department of the Interior, Department of Investigations, 7204, Dec., 1968.

8. Walter, C. Edwards, "Practical Refuse Recycling," pending publication by ASCE.

9. Haynes, J. and Ledbetter, W. B., "Incinerator Residue in Bituminous Base Construction," FHWA-RD-76-12, Federal Highway Administration Offices of Research and Developement, Washington, D. C., Dec. 1975.

10. ____________, ASTM Designation D2041, 1975 Annual Book of ASTM Standards, Part 15, pp.484-486.

11. ____________,ASTM Designation D2726, 1975 Annual Book of ASTM Standards, Part 15, pp. 633-634.

12. Breen, J. J., and Stephens, J. E. "Split Cylinder Test Applied to Bituminous Mixtures and Low Temperatures," ASTM Journal of Materials, Vol. 1, Mar., 1966, pp66-67.

13. Asphalt Institute, "Bituminous Aggregate Base Course: Survey of State Practices," Highway Research Board Special Report 117, 1971.

14. Britton, S. C., Bynum, D., Jr., and Ledbetter, W. B., "Evaluation of Asphalt Structural Performance," Research Report 127-4(F), Research Study 2-8-69-127, Texas Transportation Institute, Texas A&M University, College Station, May, 1971.

☆ U.S. GOVERNMENT PRINTING OFFICE 1979 -627-848/1927