FINAL REPORT

EFFECT OF SOME AGGREGATE CHARACTERISTICS ON THE FATIGUE BEHAVIOR OF AN ASPHALTIC CONCRETE MIXTURE

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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ABSTRACT

The effect of aggregate characteristics on the fatigue behavior of asphaltic mixtures was investigated by utilizing a laboratory constant deflection, flexural fatigue test. Coarse aggregate characteristics such as surface texture, rugosity, and flakiness index, were evaluated and attempts were made to correlate these with fatigue behavior.

Since previous work had indicated that aggregate shape and roughness could affect the fatigue life, it was hoped that the particle index, which accounts for all aggregate physical characteristics, would correlate with fatigue life.

No correlation between particle index and fatigue life was found; however, extremely high values of particle index may indicate a tendency toward low fatigue life.

There was no significant difference in the fatigue behavior of a mixture containing limestone aggregate and one containing limestone aggregate on which the surface texture had been roughened by acid etching.

Although high values of rugosity and flakiness can indicate a predicted low fatigue life, low values do not necessarily predict normal or high fatigue life.

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INTRODUCTION

Variables affecting the fatigue behavior of asphaltic mixtures have been investigated to determine their importance. Some of them are: temperature(1), aggregate gradation(2), binder type and hardness (1,3,4,5,6), asphalt content(1,2,6), air void content(2,7), specimen stiffness(7), and aggregate type(8).

The effect of aggregate type has been investigated only to a limited extent. Monismith(8) discovered that a mixture containing crushed granite performed better than a mixture containing uncrushed gravel in a constant stress test mode. Jimenez and Gallaway (6) found that "sheet asphalt mixes made with aggregates of rough surface texture may produce a longer fatigue life than comparable mixes with smooth surface texture." The test mode used was neither strictly stress nor strain controlled. NCHRP Report 39 (9) reveals that increased aggregate angularity and roughness will usually result in a longer fatigue life under a constant stress test and a shorter fatigue life under a constant strain test.

A study by the present author (10) revealed that aggregate shape can have a significant influence on the fatigue life of a mixture. In this case a mixture containing slabby aggregate particles (slate) had a significantly shorter fatigue life than did a mixture containing spherical aggregate particles under a constant strain testing mode.

Since it has been observed that aggregate type can affect fatigue results, detailed information should be available in order that an aggregate that prompts early fatigue-failure in a mixture will not be used. This investigation was designed to collect some such information.

PURPOSE AND SCOPE

The purpose of this investigation was to determine the influence of some aggregate characteristics on the fatigue life of an asphaltic surface mixture under repetitions of constant strain. The aggregate characteristics evaluated were: surface texture, rugosity, flakiness index, which is a measure of shape, and particle index (11), which is a numerical indication of the combined aggregate characteristics. It was hoped that the particle index would provide a quick method of predicting the effect of aggregate characteristics on the fatigue life of a mixture.

Seven mixes containing different aggregates were tested under constant strain repetitions (fatigue) in the laboratory.

METHOD OF APPROACH

Surface Texture

Two asphaltic mixes were tested to determine the effect that aggregate surface texture had on their fatigue life. Both mixes contained limestone aggregate; in one the aggregate was etched, in the other it was not. This utilization of the same basic aggregate for both mixes allowed the surface texture to be changed while other characteristics such as shape and angularity were held constant.

Particle Index

Five mixes were tested under fatigue type loading and the coarse aggregates were evaluated by the particle index. Aggregate characteristics such as shape, angularity, and surface texture can be defined numerically by the particle index, which eliminates unreliable verbal descriptions. The particle index indicates these aggregate characteristics by the rate of change of voids in a uniform-sized aggregate that is rodded in a rhombohedral mold.

Rugosity and Flakiness Index

Rugosity, which is an aggregate roughness indicator, and flakiness index, which is a shape measure, were also computed for each aggregate.

MATERIALS

Surface Texture Investigation

Mix #1. Limestone aggregate — coarse and fine.

Mix #2. Etched + #4 limestone aggregate and unetched fine limestone.

85-100 penetration Esso asphalt cement.

Figure 1 illustrates the surface texture difference for etched and unetched particles.

Particle Index Investigation

The five aggregates used in the particle index investigation are shown in Figure 2 and listed below.

Mix #1. Coarse uncrushed gravel and fine limestone.

Mix #2. Coarse crushed gravel and fine limestone.

Mix #3. Coarse gravel, one-half crushed, and fine limestone.

Mix #4. Coarse crushed basalt and fine limestone.

Mix #5. Coarse slag and fine limestone.

85-100 penetration Esso asphalt cement.

Figure 1. Etched (top) and unetched limestone particles (7 x magnification).

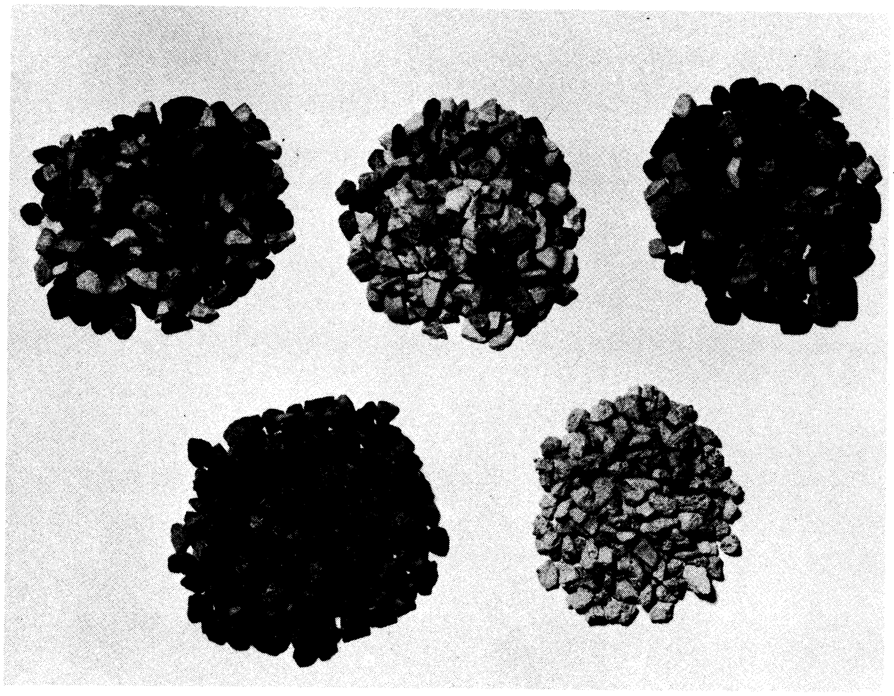

Figure 2. Aggregates (3/8") in particle index investigation. Top -- left to right -- 1/2 crushed and 1/2 uncrushed gravel, crushed gravel, uncrushed gravel. Bottom -- left to right -- basalt, slag.

PROCEDURE

Fatigue Tests

All fatigue tests were performed on 2.5" x 3" x 14" beam specimens in a constant deflection mode at room temperature, 75°F. The specimens were prepared on a modified California kneading compactor.(10) One-quarter inch was sawed from the top and the bottom of the beams to provide a smooth bearing surface, reduce stress concentrations, and provide a smooth surface for attaching crack detecting foil strips. The beam was simply supported and loaded at midspan to produce the desired deflection. The midspan deflection on the etched and unetched limestone beams was 0.007" and the deflection on the beams used in the particle index correlation was 0.008".

Failure was defined as that time when the tensile side of the beam cracked, thus cracking foil strips glued to the beam, which stopped the machine.(10)

Aggregate Surface Texture Investigation

Ideally, to determine the effect of surface texture on the fatigue life of an asphaltic mixture, fatigue comparisons should be made on mixtures containing aggregates with different surface textures but with identical shapes and angularities. The search for two aggregates with these qualities proved fruitless; therefore, it was decided to etch an impure limestone aggregate with acid to provide a different surface texture. The etched and unetched limestone aggregates had similar shape and angularity characteristics but the surface texture differed by microscopic comparison (Figure 1).

The limestone material retained on the #4 sieve was soaked in 0.5 N HCl solution for 20 minutes to give a roughened, etched surface texture. Trial and error indicated that a 20 minute soaking time produced surface impurity protrusions that did not break off when the materials were mixed and handled. After the 20 minute etching period the aggregate was thoroughly washed to remove the acid residue.

The aggregate was then recombined to yield a surface type mixture (Table I) for each test specimen. It was heated to 300°F and combined with 85-100 penetration asphalt cement heated to 275°F. The aggregate and asphalt were mixed in a Reynolds mixer for 2.5 - 3.0 minutes.

TABLE I

GRADATION OF ASPHALTIC MIXTURES

Sieve	% Passing
1/2	100
3/8	90
4	60
8	45
30	22.5
50	14.5
100	9.0
200	5.0

A series of Marshall tests were performed on each mix to obtain a stability-asphalt content curve, and the asphalt content used for each aggregate type was that yielding the maximum Marshall stability.

Each beam tested for fatigue life had a foil strip glued approximately one-half inch from each edge on the sawed tensile side (shown in Figure 3). These strips were connected in parallel with the deflection timing mechanism so that the fatigue machine automatically stopped when a fatigue crack formed and broke both foil strips.

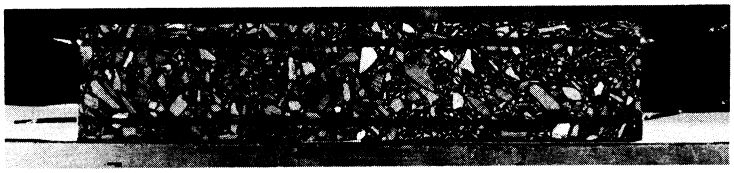

Figure 3. Aluminum foil strips on bottom (tensile side) of beam.

In addition to the fatigue life tests, the structural breakdown of the beam caused by cyclic straining was measured by subjecting the fatigued beams to a destructive flexural test and obtaining the modulus of rupture. The flexure type test was carried out on simply supported beams with a center line deflection rate of 0.5" per minute. The modulus of rupture was computed from the maximum load supported by the beam.

Particle Index Investigation

Particle index is a numerical scale that indicates roughness, angularity, and shape characteristics. Polished aluminum spheres have a particle index equal to zero. A higher particle index indicates that any or all of the physical characteristics, roughness, angularity and shape, have been increased.

Five asphaltic mixtures were made using coarse aggregates, +4 material, with particle indices ranging from 8.3 to 17.1 for uncrushed gravel and slag respectively.

As was the case for the texture investigation, the asphalt content was that which provided the highest Marshall stability.

Rugosity and Flakiness Index

The flakiness index(12), and rugosity(13), were also obtained on the coarse aggregate since they were easy to obtain and it was hoped that they might provide additional information on particle [redacted] physical characteristics.

RESULTS

Aggregate Surface Texture Investigation

The average fatigue lives of the mixtures containing the etched and unetched limestone aggregates were 108,470 and 103,958 cycles respectively, and the standard deviations were 106,823 and 57,151 cycles respectively. The fatigue life standard deviation of the mixture containing the etched aggregate was higher than usual. The etching process could have caused the mixture to have more fatigue variability. Because of the testing variation, there was no statistical difference in the two values; therefore, it appears that the increase in aggregate surface texture caused by etching did not affect the fatigue performance significantly.

Jimenez and Gallaway (6) observed a difference in the fatigue performance of mixtures made from smooth and rough textured aggregates. Also Monismith (8) observed that the fatigue performances of mixtures containing crushed granite and uncrushed gravel were different. It is not possible to compare the results of those investigations with the results presented in this report since two different modes of testing (constant stress vs. constant strain) were used; however, those investigations did indicate that aggregate type and possibly surface texture may have an influence on the fatigue performance of an asphaltic mixture. It will also be pointed out later in this discussion that the surface roughness of the slag aggregate tested in this investigation was believed to be responsible for low fatigue life.

The plot of modulus of rupture versus cycles of constant strain (Figure 4) illustrates the closeness of results for both the etched and unetched mixtures. These data point out that approximately a twenty percent reduction of the original modulus of rupture occurred when a crack formed (fatigue life).

Particle Index Investigation

The phase of the investigation dealing with the correlation between particle index and fatigue life yielded rather disappointing results; however, some relevant information was obtained.

Four mixes with particle indices ranging from 8.3 to 15.4 showed no significant difference in fatigue life (Table II and Figure 5). The fifth mix, containing slag with a particle index of 17.1, showed a much reduced fatigue life (26,565 cycles).

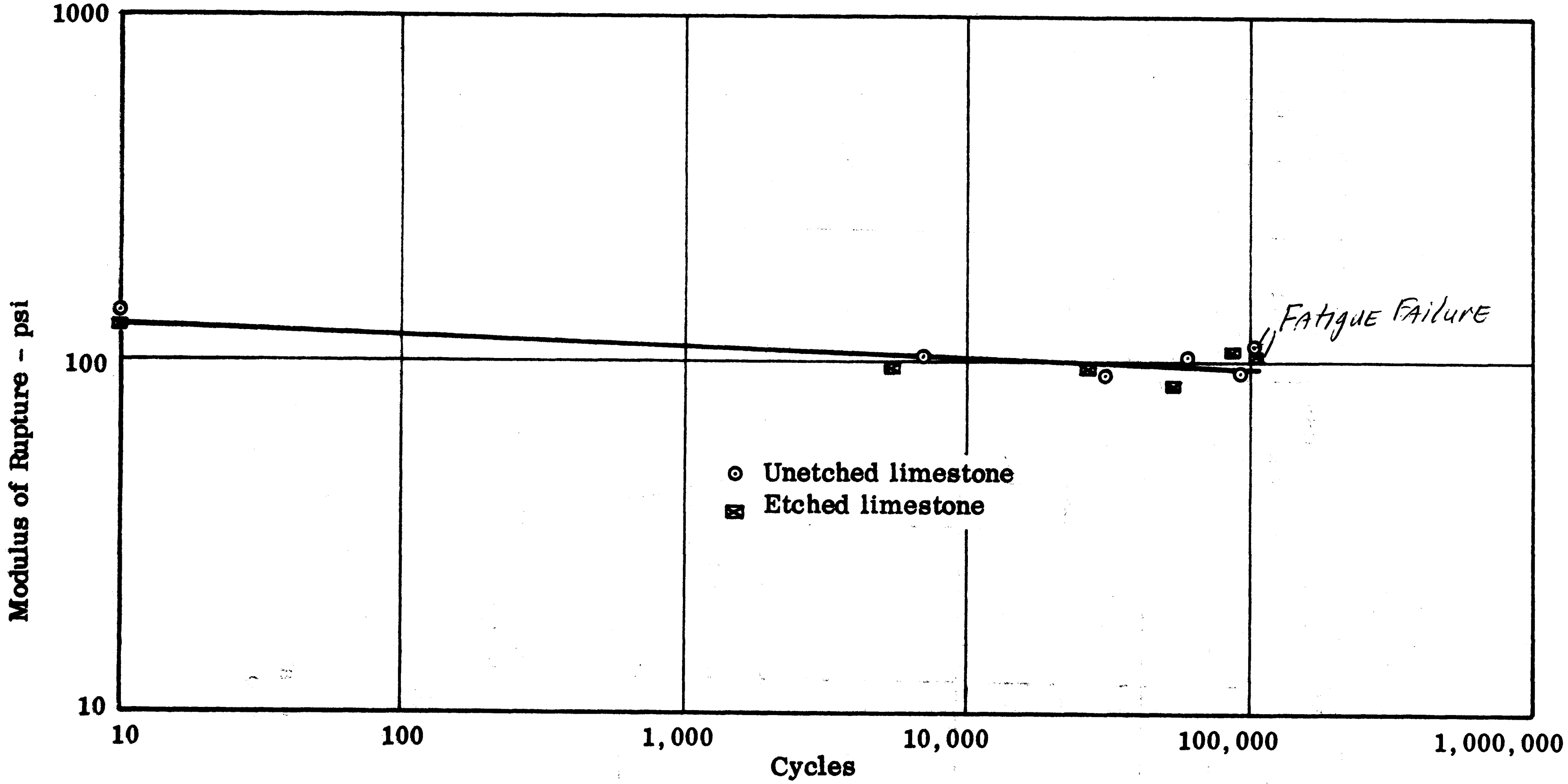

Figure 4. Strength-fatigue curves for asphaltic mixtures containing etched and unetched limestone.

TABLE II

AGGREGATE CHARACTERISTICS AND FATIGUE LIFE OF ASPHALTIC MIXTURES

Aggregate Type	Particle Index of +4 Aggregate	Rugosity	Flakiness Index	Average Fatigue Life	Fatigue Life Standard Deviation
		cm^3/cm^2		cycles	cycles
Uncrushed Gravel	8.3	1.27	12.0	166,112	70,279
Crushed Gravel	12.6	2.45	16.3	153,032	58,918
1/2 Crushed Gravel 1/2 Uncrushed Gravel	11.0	1.86	14.1	115,724	39,122
Basalt	15.4	1.99	26.2	135,639	38,561
Slag	17.1	4.67	19.1	26,565	11,923

Note: Appendix A contains fatigue beam properties

A slate mixture tested in a previous study (10) had a particle index of 17.7 and also a low fatigue life. The fatigue life was 57,728 cycles for a 0.007" deflection and the corrected fatigue life for a 0.008" deflection was computed to be approximately 40,000 cycles by the formula

$$N_8 = N \left(\frac{\epsilon 7}{\epsilon 8} \right)^n$$

where N = number of cycles at a specified strain level, ϵ = strain, and n = slope of the fatigue strain line. Two aggregates with particle indices greater than 17 displayed low fatigue life.

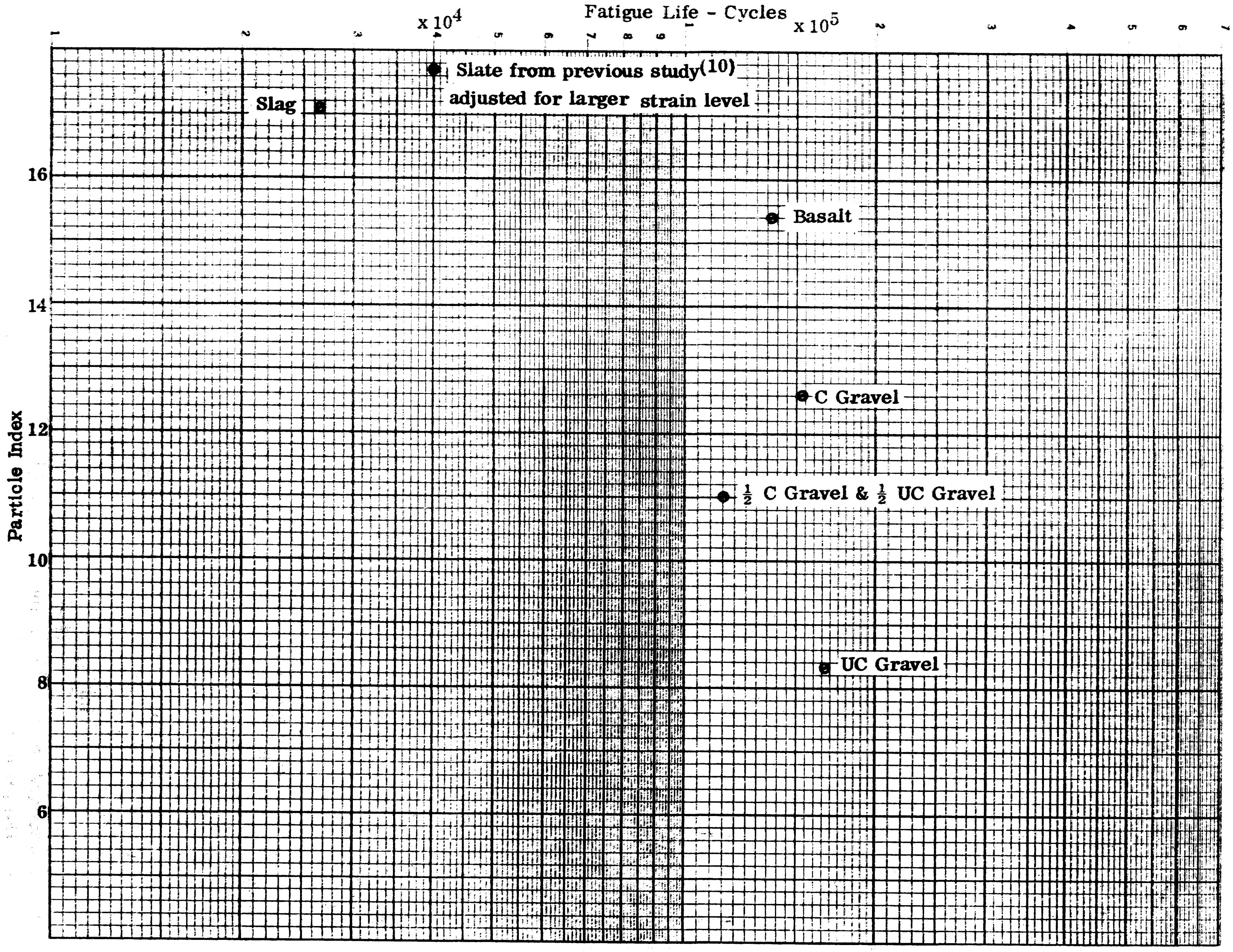

Figure 5. Particle Index of +4 aggregate vs. fatigue life of asphaltic mixtures in constant deflection tests.

Although the mix that performed poorly did exhibit the highest particle index (17.1), the mix containing aggregate having the next highest particle index (15.4) had a fatigue life that was approximately five times that of the slag mixture. It is quite possible that particle index may be indicative of the fatigue performance; however, from the quantity of data available it appears that the lower limiting value of the particle index is not defined precisely enough to predict satisfactory and unsatisfactory mixes with regard to fatigue susceptibility.

Rugosity and Flakiness Index

Rugosity and flakiness index were also evaluated. From these determinations it was possible to gain some insight into the influence of particle shape and roughness on the particle index.

For example, the highest particle index of 17.1 for the slag resulted primarily from surface texture since it had a high rugosity ($4.67 \frac{cm^3}{cm^2}$) and only a moderate flakiness index (19.1). The basalt had a particle index of 15.4, influenced primarily by the particle shape (flakiness index = 26.2); the rugosity was relatively low at $1.99 \frac{cm^3}{cm^2}$. From a visual inspection it was speculated that the angularity may also have had a major influence on the particle index, however, it was not measured here. Surface texture and shape appeared to have an equal influence on the particle index for the remaining three gravel mixes. Rugosity is plotted against fatigue life in Figure 6. Of the five aggregates that were tested the aggregate with the highest rugosity did exhibit a low fatigue life.

Slate aggregate used in a previous study possessed low rugosity and low fatigue life. This means that rugosity will not indicate fatigue life.

Four of the aggregates had rugosities ranging from 1.27 to $2.45 \frac{cm^3}{cm^2}$, however, the slag had a rugosity of $4.67 \frac{cm^3}{cm^2}$ and an average fatigue life of only 26,565 cycles. Roughness verified by a high rugosity value is believed to be responsible for the low fatigue life of the slag mixture.

Results of the etched and unetched limestone mixtures indicated that a small surface texture change had little effect on fatigue life; however, results of tests on the slag mixture indicate that a high degree of surface roughness may have a significant effect on fatigue performance.

A previous study by the author (10) had indicated that shape as measured by the flakiness index did not influence fatigue life unless the aggregate particles were very flaky. A slate mix (flakiness index = 56) had a lower fatigue life than mixes containing aggregates with less flaky shapes. Therefore, for this investigation with mixes containing aggregates with flakiness indices less than 27, one would expect the influence of shape on the fatigue life to be very insignificant. Figure 7 is a plot of flakiness index versus log cycles to failure.

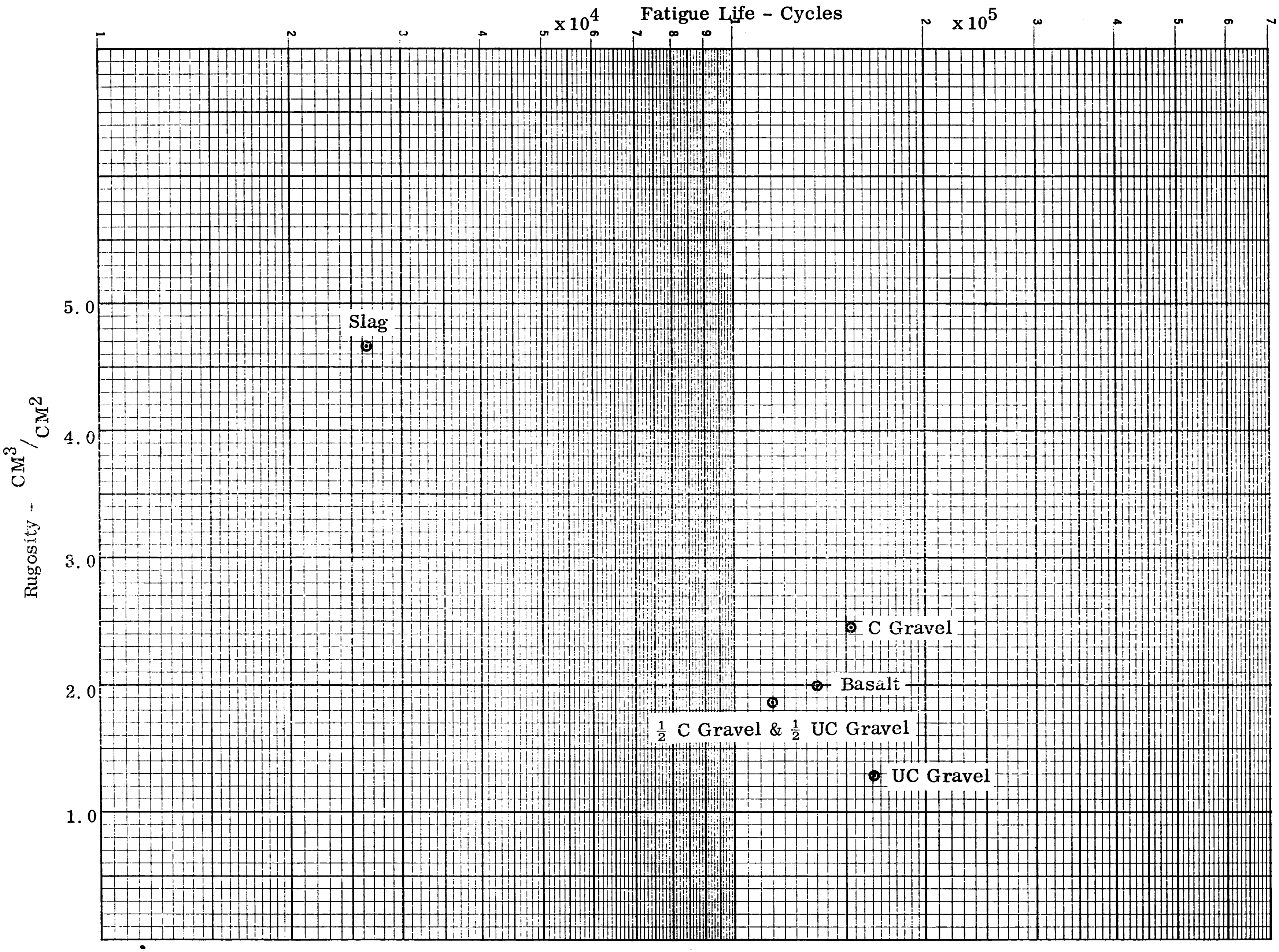

Figure 6. Rugosity of +5/8" aggregate vs. fatigue life of asphaltic mixtures in constant deflection tests.

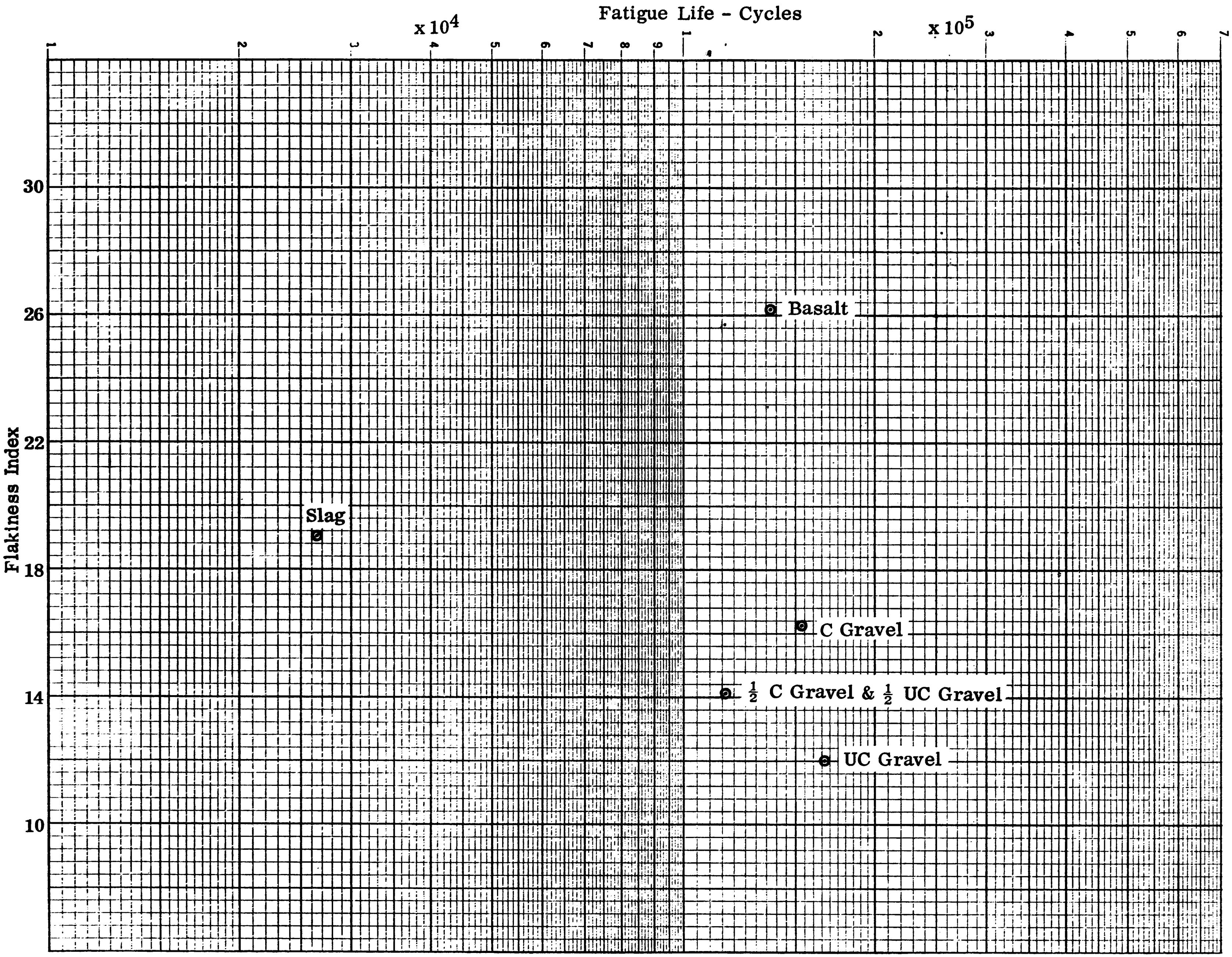

Figure 7. Flakiness index of +4 aggregate vs. fatigue life of asphaltic mixtures in constant deflection tests.

The random occurrence of the results indicates no relation between flakiness index and fatigue life for the mixes tested.

A low fatigue life can be caused by both extremely high flakiness index values (slate) or high rugosity values (slag). Both flakiness index and rugosity tests would have to be performed on a single aggregate in order to examine the possibility of early fatigue failure. Particle index appears to be preferable from the standpoint that it measures both flakiness and rugosity.

CONCLUSIONS

1. There was no significant difference in the fatigue lives of the etched and unetched limestone mixes; therefore it appears that the increase in aggregate surface texture caused by etching did not affect the fatigue performance.
2. There was not a correlation between particle index and fatigue life of the asphaltic mixtures tested in a constant strain mode.
3. Extremely high values of particle index (greater than 17.0) for an aggregate may indicate a tendency toward low fatigue life of an asphaltic mixture in a constant strain test.
4. Roughness as measured by rugosity is believed to be responsible for low fatigue life in the slag asphaltic mixture.
5. The effect of aggregate type on the fatigue life of the asphaltic mixtures was negligible for aggregates normally used; however, extremely rough or odd shaped aggregates may affect the fatigue life as in the slag mixture.

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APPENDIX A

Fatigue Beam Properties

Aggregate	Asphalt Content % Total Weight	Density pcf	Voids Total Mix
Uncrushed Gravel	5.5	148.5	5.2
Crushed Gravel	5.75	149.9	5.3
½ Crushed Gravel ½ Uncrushed Gravel	5.6	147.2	5.2
Basalt	5.5	154.8	5.3
Slag	7.25	138.1	10.4
Arch Marble	5.5	147.9	5.0
Etched Arch Marble	5.75	147.6	5.0