Effects of Asphalt Properties on Indirect Tensile Strength

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The indirect tensile test on asphalt concrete mixes is a frequently used procedure for assessing likely pavement performance. Currently, the indirect tensile test is most commonly used for providing information on moisture susceptibility. However, the indirect tensile test may also be used to determine engineering properties needed for elastic and viscoelastic analyses and for evaluating thermal cracking, fatigue cracking, and potential problems with tenderness. Given the importance of this test, there appears to be a lack of information on the factors that determine indirect tensile strength (IDTS) of asphalt mixes. Consequently, the effects of asphalt composition and physical properties on IDTS values were obtained. Mixes were made with 15 different types of asphalt and with 2 different types of aggregate (traprock and gravel). Asphalt composition was characterized by gel permeation chromatographic analysis. The penetration of the thin-film oven test residue and IDTS values were strongly correlated. The IDTS values increase as penetration decreases. Asphalt composition also plays a significant role in determining the IDTS values of traprock mixes. Asphalt composition seems to account for differences of up to 55 percent in IDTS values of traprock mixes. However, the effect of asphalt composition on gravel mixes appears to be much less pronounced.

The indirect tensile test on asphalt concrete mixes is commonly used to assess moisture susceptibility. However, the indirect tensile test may also be used to determine engineering properties needed for elastic and viscoelastic analyses, and for evaluating thermal cracking and fatigue cracking (*1*). Button and his associates (*2*) have used this test as part of a system of evaluating mixes for problems with tenderness.

Little information exists about the factors that determine indirect tensile strength (IDTS) of a mix. Some reports (*3–5*) have examined how IDTS values vary with mix properties such as air void and asphalt content. But few reports concern the relationship between asphalt properties and IDTS values (*6*). The possible effects of asphalt composition have not been examined at all.

Some of these factors, mainly the effects of asphalt properties on IDTS values, are examined here. The asphalt properties considered are consistency and composition. Mixes were made with 15 different asphalts from various sources nationwide. Asphalt composition was characterized by gel permeation chromatographic (GPC) analysis.

Fifteen asphalts from six suppliers were used for this project. These asphalts are characterized in Table 1. Details of the test programs for the asphalts and the asphalt mixes are discussed in the following sections.

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ASPHALT CEMENT TEST PROGRAM

The program of physical tests included viscosity (140°F) and penetration (77°F) ratings for all 15 asphalts and for residues of the asphalts after thin-film oven aging. The compositional test consisted of GPC analyses.

The GPC system included three ultrastyragel columns connected as specified in the order of 1,000, 500, and 500 Angstrom pore size. Tetrahydrofuran (THF) was used as both the solvent and the mobile phase in the system. Fifty microliters of a 0.5 percent asphalt solution was injected and allowed to flow at a rate of 1 mL/min through the columns. The detector used was a multiwavelength ultraviolet detector that was set at a wavelength of 290 nm.

GPC parameters were obtained from the GPC profiles using a modified form of a procedure that was developed at Purdue University (*7*). The procedure used in this project consisted of dividing the GPC profile into 12 equal-time segments, as opposed to the 8 unequal-time segments originally used (see Figure 1). The resulting GPC parameters, designated $X1$ to $X12$, are the percentages of total area under the curve in each segment. Molecular size can be assumed to decrease from Segment 1 to Segment 12. The GPC parameters represent the proportion of asphalt molecules of a given size. This interpretation should be applied with caution, however, because many factors affect the apparent size of an asphalt molecule (*7*).

ASPHALT CONCRETE MIX TEST PROGRAM

Eight different types of asphalt concrete (AC) mixes were made for each of the 15 asphalts. Half of the mixes were made with traprock and the other half with a river gravel. Mixes were made with two different asphalt contents (4.8 and 5.5 percent) and were compacted to two different air void contents (6 and 8 percent), resulting in a total of four types of mixes for each aggregate. Two replicates of each type of mix were tested.

The required degree of compaction was obtained by using a gyratory compactor in a constant high mode. The gradation of the mixes was the middle gradation of the Connecticut Class II mix, as follows:

Sieve Size	*Percent Passing*
½ in.	100
⅜ in.	80
#4	67
#8	52
#50	17
#200	5

Table 2 presents data on the specific gravity and absorption rate of the aggregates.

TABLE 1 ASPHALTS USED IN PROJECT

Asphalt No.	Grade	Supplier	State
NE5	AC-5	New Bituminous	Rhode Island
NE10	AC-10	New Bituminous	Rhode Island
NE20	AC-20	New Bituminous	Rhode Island
D5	AC-5	Diamond Shamrock	Texas
D10	AC-10	Diamond Shamrock	Texas
D20	AC-20	Diamond Shamrock	Texas
A5	AC-5	Ashland	Kentucky
A10	AC-10	Ashland	Kentucky
A20	AC-20	Ashland	Kentucky
E5	AC-5	Edgington	California
E20	AC-20	Edgington	California
CAG5	AC-5	Guyott	Connecticut
CAG20	AC-20	Guyott	Connecticut
CP10	AC-10	Chevron	New Jersey
CP20	AC-20	Chevron	Connecticut

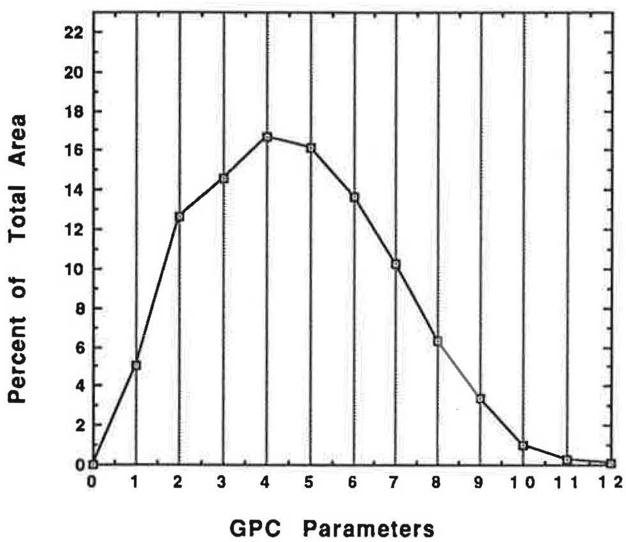

FIGURE 1 Typical GPC profile.

The IDTS value of each mix was determined at room temperature (about 75°F) using the Marshall test apparatus. The test frame for this procedure consisted of two curved loading strips, each 0.5 in. wide. The load was applied at a rate of 2 in./min, and the load at failure was recorded.

RESULTS

The results of the physical tests and the GPC analyses for the 15 asphalts are presented in Tables 3 and 4, respectively. A sample of the GPC profiles is also shown in Figure 1. Tables 5 and 6 present the indirect tensile test results for the AC mixes.

Regression analysis was used to evaluate the relationship between IDTS and the asphalt properties. The results of these analyses are used to discuss the effects of asphalt consistency and composition on IDTS in the following sections. The effects of aggregate type and of asphalt and void content are also discussed.

TABLE 2 SPECIFIC GRAVITY AND ABSORPTION OF AGGREGATES

	Specific Gravity		
Aggregate Type	Bulk	Apparent	Absorption (%)
Coarse fraction			
Trap	2.89	2.97	0.96
Gravel	2.63	2.73	1.39
Fine fraction			
Trap	2.84	3.03	2.27
Gravel	2.60	2.69	1.26

Effect of Consistency

A summary of the results of regression analyses relating IDTS values to the various measures of consistency is presented in Table 7. These results show that the penetration (at 77°F) and viscosity (at 140°F) of the original asphalt correlated with IDTS. The penetration (at 77°F) and viscosity (at 140°F) of the thin-film oven test (TFOT) residue also correlated significantly. However, the best correlation (highest r^2 value) was obtained using penetration (77°F) of the TFOT residue for all eight mix types.

From a theoretical point of view, these results are not unexpected. Because of the similarity in test temperatures, penetration at 77°F would be expected to give better correlations with tensile strength than would viscosity at 140°F. In addition, the consistency of the TFOT residue is probably closer to that of the asphalt in the mix than is the consistency of the original asphalt.

These results, though not surprising, do suggest that the relationship between asphalt and mix properties must be fully understood in terms of the characteristics of the asphalt in the mix rather than those of the original asphalt. Unfortunately, no tests were run on asphalts extracted from the mixes.

More detailed results of the regression analyses for penetration of the TFOT residue and IDTS are presented in Table 8 for the eight types of mixes. The relationship between these two variables is also shown in Figures 2–9 for each of the mixes. In all cases, the regression functions show that IDTS increases as penetration decreases. However, the slope of this relationship is significantly affected by aggregate type. The slope varied from 0.74 to 0.82 for traprock, and from 1.00 to

TABLE 3 PHYSICAL PROPERTIES OF TEST ASPHALTS

	Original Asphalt		TFOT Residue	
Asphalt No.	Penetration 0.1 dm, 77°F	Viscosity p, 140°F	Penetration 0.1dm, 77°F	Viscosity p,140°F
NE5	187	586	109	1344
NE10	110	1035	79	2155
NE20	68	1945	58	3957
D5	203	424	133	753
D10	122	896	78	1551
D20	70	2237	57	3859
A5	114	538	97	1033
A10	96	1096	58	1816
A20	74	2023	54	3837
E5	140	547	88	1107
E20	55	1711	38	3572
CAG5	177	481	126	1224
CAG20	77	2149	54	4452
CP10	117	1089	78	2947
CP20	91	1926	55	5449

TABLE 4 RESULTS OF GPC ANALYSES

Asphalt No.	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12
N5	5.02	12.65	14.56	16.67	16.17	13.63	10.25	6.29	3.40	1.05	0.26	0.05
TN5	5.38	13.80	15.14	16.54	15.91	13.30	9.89	5.89	3.08	0.87	0.17	0.03
N10	4.18	12.62	15.26	17.68	17.15	13.94	9.70	5.53	2.82	0.86	0.19	0.03
TN10	10.92	15.97	14.95	15.61	14.84	11.92	8.20	4.65	2.20	0.63	0.11	0.01
N20	3.95	12.50	15.44	18.42	17.93	14.04	9.20	5.03	2.45	0.80	0.20	0.04
TN20	8.59	16.01	15.46	16.43	15.89	12.42	8.03	4.33	2.01	0.69	0.13	0.02
D5	5.11	14.87	19.57	21.07	17.84	11.35	5.96	2.58	1.03	0.45	0.14	0.03
TD5	5.98	16.42	20.01	20.46	17.01	10.71	5.54	2.36	0.94	0.41	0.12	0.02
D10	5.02	15.10	19.67	20.93	17.63	11.29	6.01	2.65	1.09	0.43	0.14	0.03
TD10	6.36	16.65	19.92	20.12	16.69	10.62	5.60	2.44	1.00	0.44	0.14	0.03
D20	5.44	15.38	19.63	20.63	17.35	11.19	5.98	2.66	1.11	0.45	0.15	0.03
TD20	7.01	17.38	20.25	20.19	16.24	10.00	5.30	2.22	0.89	0.38	0.12	0.03
A5	1.11	10.40	14.95	21.47	22.04	15.12	8.42	4.00	1.74	0.54	0.13	0.03
TA5	3.11	11.74	15.48	20.61	20.94	14.35	7.87	3.66	1.56	0.53	0.13	0.02
A10	2.64	10.30	14.10	19.15	20.40	15.60	9.60	4.95	2.30	0.74	0.16	0.03
TA10	3.34	11.54	14.63	18.79	19.70	14.92	9.14	4.71	2.14	0.87	0.19	0.03
A20	4.55	12.38	14.99	18.21	18.44	14.21	9.10	4.90	2.29	0.74	0.16	0.03
TA20	5.40	13.27	15.42	18.11	18.10	13.78	8.70	4.55	2.03	0.57	0.07	0.00
E5	1.00	5.84	11.90	18.20	20.41	18.64	13.80	6.71	2.66	0.69	0.13	0.02
TE5	2.28	9.25	13.74	17.57	18.81	17.01	12.43	5.85	2.25	0.68	0.12	0.02
E20	1.27	6.16	12.41	18.83	20.98	18.73	12.88	5.80	2.20	0.59	0.12	0.02
TE20	2.54	8.86	13.71	18.08	19.50	17.35	11.90	5.31	1.95	0.67	0.13	0.02
CAG5	4.22	12.32	15.11	17.87	17.44	14.06	9.64	5.48	2.77	0.86	0.19	0.03
TCAG5	5.35	13.49	15.15	17.28	16.77	13.51	9.22	5.23	2.60	1.12	0.23	0.04
CAG20	4.18	12.11	14.54	17.00	16.58	14.02	10.44	6.36	3.35	1.04	0.25	0.05
TCAG20	5.47	13.86	15.11	16.60	15.90	13.31	9.77	5.85	3.01	0.89	0.19	0.03
CP10	5.36	13.13	15.72	17.20	15.91	13.03	9.65	5.75	3.01	0.96	0.23	0.05
TCP10	9.26	15.22	15.48	15.88	14.63	12.02	8.84	5.15	2.58	0.80	0.15	0.02
CP20	4.73	12.93	15.64	17.21	16.21	13.52	9.84	5.70	2.94	0.94	0.27	0.05
TCP20	6.95	14.62	15.66	16.64	15.44	12.64	9.14	5.26	2.64	0.80	0.18	0.03

TABLE 5 IDTS OF TRAPROCK MIXES

Asphalt Number	Indirect Tensile Strength(psi) 8%Voids 4.8%AC	8%Voids 5.5%AC	6%Voids 4.8%AC	6%Voids 5.5%AC
NE5	38	37	37	39
NE10	57	62	59	58
NE20	62	62	70	69
D5	39	36	45	42
D10	55	58	66	57
D20	86	86	85	80
A5	39	33	41	33
A10	74	54	67	59
A20	77	77	87	85
E5	57	52	49	48
E20	106	99	111	108
CAG5	48	46	50	43
CAG20	58	65	67	66
CP10	46	48	50	43
CP20	75	72	78	78
Average	61	59	64	61

TABLE 6 IDTS OF GRAVEL MIXES

Asphalt Number	Indirect Tensile Strength (psi) 8%Voids 4.8%AC	8%Voids 5.5%AC	6%Voids 4.8%AC	6%Voids 5.5%AC
NE5	65	52	62	63
NE10	91	71	78	71
NE20	101	93	108	103
D5	45	39	40	38
D10	80	77	75	83
D20	136	132	142	129
A5	49	47	48	47
A10	74	76	78	83
A20	101	96	72	108
E5	57	48	61	60
E20	179	155	138	133
CAG5	45	42	42	42
CAG20	97	112	120	121
CP10	58	50	67	67
CP20	108	89	100	103
Average	86	79	82	83

TABLE 7 RESULTS OF REGRESSION ANALYSES: IDTS VERSUS ASPHALT CONSISTENCY

Mix Type	R-squared for Independent Variable: Penetration 77°F, original	Viscosity 140°F, original	Penetration 77°F, TFOT	Viscosity 140°F, TFOT
Trap 8%voids, 4.8%AC	0.69	0.60	0.78	0.50
Trap 8%voids, 5.5%AC	0.71	0.73	0.77	0.65
Trap 6%voids, 4.8%AC	0.75	0.71	0.81	0.62
Trap 6%voids, 5.5%AC	0.72	0.75	0.81	0.66
Gravel 8%voids, 4.8%AC	0.76	0.75	0.82	0.66
Gravel 8%voids, 5.5%AC	0.84	0.82	0.86	0.67
Gravel 6%voids, 4.8%AC	0.76	0.80	0.80	0.71
Gravel 6%voids, 5.5%AC	0.81	0.89	0.89	0.79

1.11 for the gravel mixes. To a smaller extent, the slope was also affected by asphalt content. Larger slope values were obtained for those mixes with the higher asphalt content (5.5 percent).

The difference in slopes means that a change in penetration will cause a much larger change in the IDTS of a gravel mix than that of a traprock mix. Because penetration of the asphalt in the mix will change with temperature, another interpretation of this result may be that mixes with different aggregates have different temperature susceptibility with respect to IDTS. If this is the case, then the temperature susceptibility of the gravel mix is greater than that of traprock mix. This hypothesis needs to be verified by tests on the mixes at different temperatures.

TABLE 8 RESULTS OF REGRESSION ANALYSES: IDTS VERSUS PENETRATION OF TFOT RESIDUE (RPEN77)

Mix Type	Regression Model	r-squared
Trap 8%voids, 4.8%AC	log(IDTS) = -0.74 * log(RPEN77) + 7.23	0.78
Trap 8%voids, 5.5%AC	log(IDTS) = -0.78 * log(RPEN77) + 7.38	0.77
Trap 6%voids, 4.8%AC	log(IDTS) = -0.76 * log(RPEN77) + 7.39	0.81
Trap 6%voids, 5.5%AC	log(IDTS) = -0.82 * log(RPEN77) + 7.57	0.81
Gravel 8%voids, 4.8%AC	log(IDTS) = -1.02 * log(RPEN77) + 8.76	0.82
Gravel 8%voids, 5.5%AC	log(IDTS) = -1.11 * log(RPEN77) + 9.02	0.86
Gravel 6%voids, 4.8%AC	log(IDTS) = -1.00 * log(RPEN77) + 8.61	0.80
Gravel 6%voids, 5.5%AC	log(IDTS) = -1.07 * log(RPEN77) + 8.92	0.89

Note: log(IDTS) is the Natural Log of Tensile Strength
log(RPEN77) is the Natural Log of TFOT Penetration

TABLE 9 RESULTS OF REGRESSION ANALYSES: IDTS VERSUS PENETRATION OF TFOT RESIDUE (RPEN77) AND GPC PARAMETERS (*X*5 AND *X*12)

Mix Type	Regression Model	r-squared
Trap 8%voids, 4.8%AC	log(IDTS) = - 0.046 * X5 - 14.37 * X12 - 0.75 * log(RPEN77) + 8.64	0.90
Trap 8%voids, 5.5%AC	log(IDTS) = - 0.096 * X5 - 17.42 * X12 - 0.83 * log(RPEN77) + 9.92	0.93
Trap 6%voids, 4.8%AC	log(IDTS) = - 0.075 * X5 - 16.55 * X12 - 0.79 * log(RPEN77) + 9.47	0.95
Trap 6%voids, 5.5%AC	log(IDTS) = - 0.089 * X5 - 16.43 * X12 - 0.86 * log(RPEN77) + 9.93	0.95
Gravel 8%voids, 4.8%AC	log(IDTS) = - 0.030 * X5 - 1.05 * log(RPEN77) + 9.41	0.84
Gravel 8%voids, 5.5%AC	log(IDTS) = - 0.024 * X5 - 1.12 * log(RPEN77) + 9.52	0.87
Gravel 6%voids, 4.8%AC	log(IDTS) = - 0.046 * X5 - 1.03 * log(RPEN77) + 9.58	0.85
Gravel 6%voids, 5.5%AC	log(IDTS) = - 0.047 * X5 - 1.11 * log(RPEN77) + 9.93	0.94

Example: Calculation of Composition Index for mix, Trap:6%voids:4.8%AC

*COMPOSITION INDEX = -0.075 * X5 -16.55 * X12*
(GPC parameters, X5 and X12, are listed in Table 4 for each asphalt)

Effect of Composition

Stepwise regression analyses were conducted to determine the best regression model that incorporated both consistency data and compositional data. The best results for the traprock mixes were obtained with a model containing (a) TFOT penetration, (b) GPC parameter $X5$, and (c) GPC parameter $X12$. The best model for the gravel mixes was the one with (a) TFOT penetration and (b) GPC parameter $X5$.

The resulting regression models (presented in Table 6) show that, in the case of the traprock mixes, the inclusion of asphalt composition (GPC parameters) significantly improved the correlation. However, the inclusion of these parameters did little to improve the prediction for the gravel mixes.

The plots in Figures 2–9, for IDT test versus penetration (at 77°F) of the TFOT residue, show some amount of scatter about the regression function. In the case of the traprock mixes, much of this scatter or deviation from the prediction line is related to differences in composition.

TABLE 10 COMPOSITION INDEXES FOR TRAPROCK MIXES

Asphalt Number	Composition Index: 8%Voids 4.8%AC	8%Voids 5.5%AC	6%Voids 4.8%AC	6%Voids 5.5%AC
NE5	-1.46	-2.42	-2.04	-2.26
NE10	-1.22	-2.17	-1.78	-2.02
NE20	-1.40	-2.42	-2.01	-2.25
D5	-1.25	-2.24	-1.83	-2.08
D10	-1.24	-2.22	-1.82	-2.06
D20	-1.23	-2.19	-1.80	-2.04
A5	-1.45	-2.64	-2.15	-2.45
A10	-1.37	-2.48	-2.03	-2.31
A20	-1.28	-2.29	-1.88	-2.13
E5	-1.23	-2.31	-1.86	-2.15
E20	-1.25	-2.36	-1.90	-2.20
CAG5	-1.23	-2.20	-1.80	-2.05
CAG20	-1.48	-2.46	-2.07	-2.30
CP10	-1.45	-2.40	-2.02	-2.24
CP20	-1.46	-2.43	-2.04	-2.26
Range	-1.48 to -1.22	-2.64 to -2.17	-2.15 to -1.78	-2.45 to -2.02

TABLE 11 COMPOSITION INDEXES FOR GRAVEL MIXES

Asphalt Number	Composition Index: 8%Voids 4.8%AC	8%Voids 5.5%AC	6%Voids 4.8%AC	6%Voids 5.5%AC
NE5	-0.49	-0.39	-0.74	-0.76
NE10	-0.52	-0.41	-0.79	-0.81
NE20	-0.55	-0.43	-0.83	-0.84
D5	-0.54	-0.43	-0.82	-0.84
D10	-0.54	-0.42	-0.81	-0.83
D20	-0.53	-0.41	-0.80	-0.82
A5	-0.67	-0.53	-1.01	-1.04
A10	-0.62	-0.49	-0.94	-0.96
A20	-0.56	-0.44	-0.85	-0.87
E5	-0.62	-0.49	-0.94	-0.96
E20	-0.64	-0.50	-0.97	-0.99
CAG5	-0.53	-0.42	-0.80	-0.82
CAG20	-0.50	-0.40	-0.76	-0.78
CP10	-0.48	-0.38	-0.73	-0.75
CP20	-0.49	-0.39	-0.75	-0.76
Range	-0.67 to -0.48	-0.53 to -0.38	-1.01 to -0.73	-1.04 to -0.75

In order to better illustrate the effect of composition, a composition index was calculated by considering the contribution of the GPC parameters to the regression functions in Table 9. Values of composition indices for the mixes are presented in Tables 10 and 11. In addition, the amount of deviation from the regression line in Figures 2–9 was determined for each data point. The plot of deviation versus composition index indicates the contribution of composition in determining IDTS. These plots are shown in Figures 10–17.

In general, there is a significant degree of correlation between deviation and composition index for the traprock mixes but not for the gravel mixes. This correlation confirms that asphalt composition is important in determining the IDTS of the traprock mixes.

The maximum difference in composition index for a given type of mix can also be considered to be the maximum difference (on an exponential scale) in IDTS values that is attributable to composition. For the traprock, this range in IDTS values was about 0.45 for two of the four mixes. This result means that for two asphalts of the same penetration, differences in composition would cause a maximum difference in IDTS value of about 55 percent [i.e., the IDTS value of Asphalt A was 4.00 (55 psi), the IDTS value of Asphalt B was 4.45 (87 psi)]. For the gravel mixes, the range of composition index was less than 0.29 in all four cases.

For the traprock mixes, the deviation from the line increases in a positive direction as composition index increases (Figures 10–13). In other words, the penetration model underestimates the IDTS of mixes with asphalt of relatively high values of composition index (a combination of low values for the $X5$ and $X12$ parameters). Also, the composition indexes for asphalts from the same source were not necessarily of similar magnitude.

The previously discussed results for consistency suggested the need for determining the consistency of the actual asphalt in the mix to better understand the relationship between asphalt properties and the AC mix properties. Similarly, the compositional data should be that of the actual asphalt in the mix rather than that of the original asphalt. As stated before, however, no extraction was done.

Despite the shortcomings of using compositional data for the original asphalt, the results give some indication of the effect of composition on this mix property. The same techniques could be used in studying the actual asphalts from pavements, to determine how changes in asphalt properties affect pavement properties such as IDTS. However, the compositional data might not be required if the actual consistency of the asphalt in the specimen is used in the regression. This hypothesis can only be verified by further research.

Effect of Aggregate Type, Air Voids, and Asphalt Content

Aggregate type significantly affects the relationship between penetration and IDTS value, in that the slope of the relationship is larger for gravel than for a traprock mix. In effect, the gravel mix is more susceptible to temperature changes than an equivalent traprock mix with the same asphalt.

Another important difference is that the average tensile strength (see Table 5) was higher for gravel (82 psi) than for traprock (62 psi). These averages were approximately the same for each of the four combinations of air voids and asphalt content. However, the differences between gravel and traprock were not uniform for all asphalts. For example, the IDTS value of mixes with asphalt D5 was about the same (41 psi) using either gravel or traprock; however, for asphalt NE5, the strength of the gravel mix was significantly higher (61 versus 38 psi). Many other examples of this kind of variability can be observed in Table 5.

The mix properties examined in this project were air voids (6 and 8 percent) and asphalt content (4.8 and 5.5 percent). In general, tensile strength decreased as air voids and asphalt content increased (see Table 3). The differences were small, and the amount varied from asphalt to asphalt. The differences were also smaller than have been reported in some other studies (*3,4*).

Like aggregate type, asphalt content also affected the slope of the relationship between IDTS value and penetration. In all cases, high-asphalt-content mixes had higher temperature susceptibility for given tensile strength.

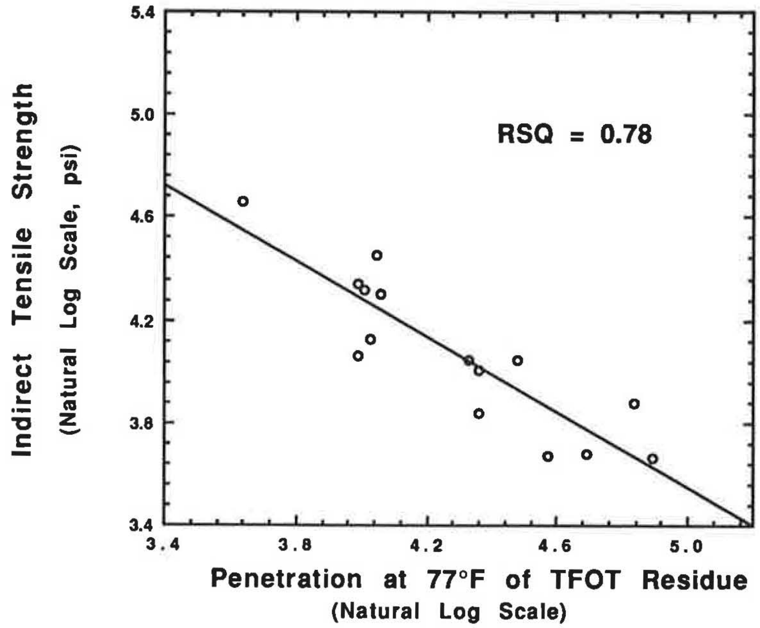

FIGURE 2 IDTS versus penetration (at 77°F) of the TFOT residue: traprock mix, 8 percent voids, 4.8 percent AC.

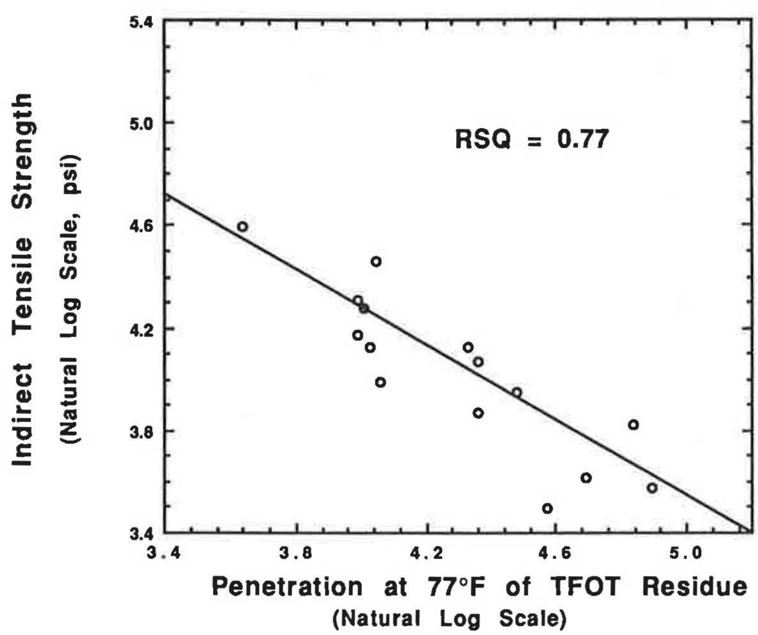

FIGURE 3 IDTS versus penetration (at 77°F) of the TFOT residue: traprock mix, 8 percent voids, 5.5 percent AC.

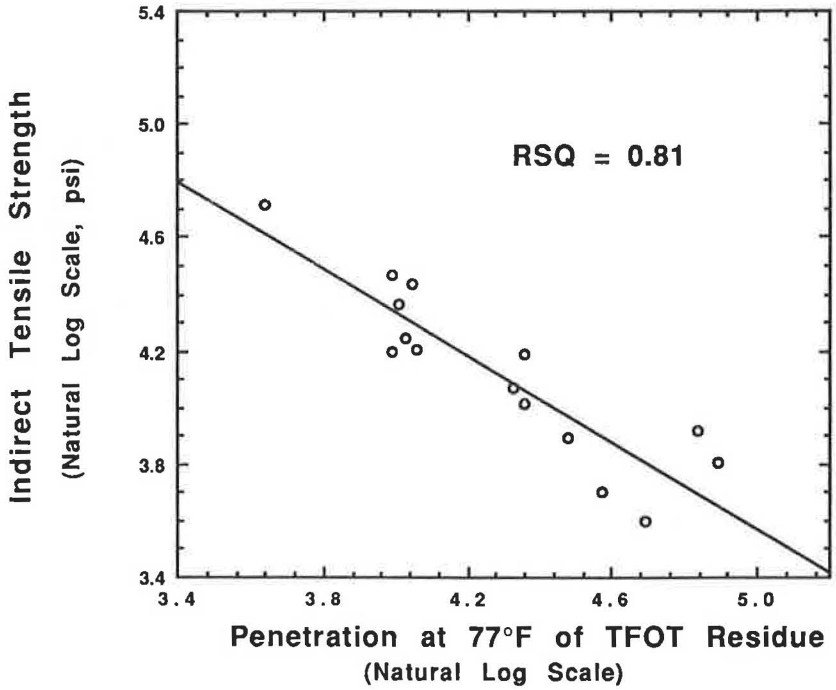

FIGURE 4 IDTS versus penetration (at 77°F) of the TFOT residue: traprock mix, 6 percent voids, 4.8 percent AC.

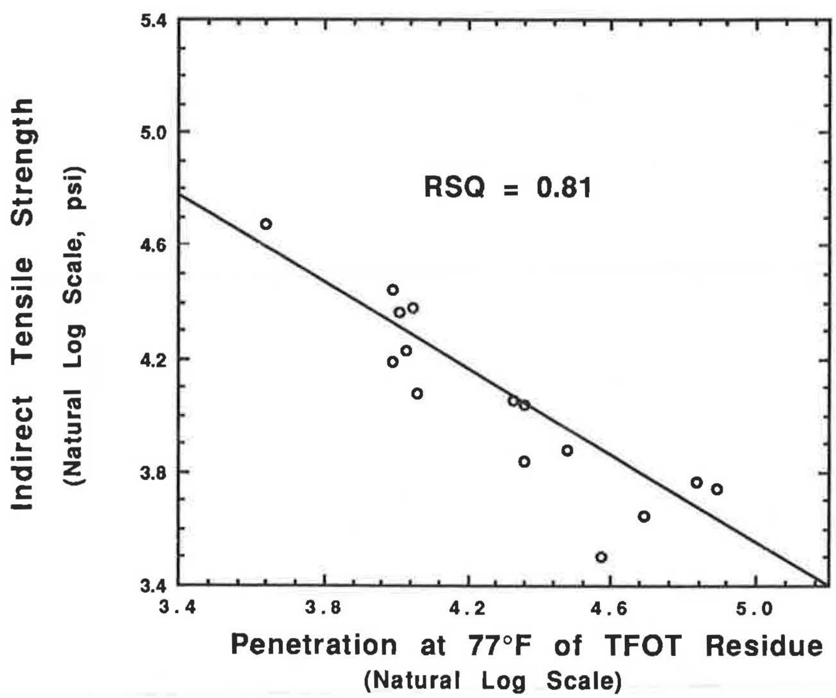

FIGURE 5 IDTS versus penetration (at 77°F) of the TFOT residue: traprock mix, 6 percent voids, 5.5 percent AC.

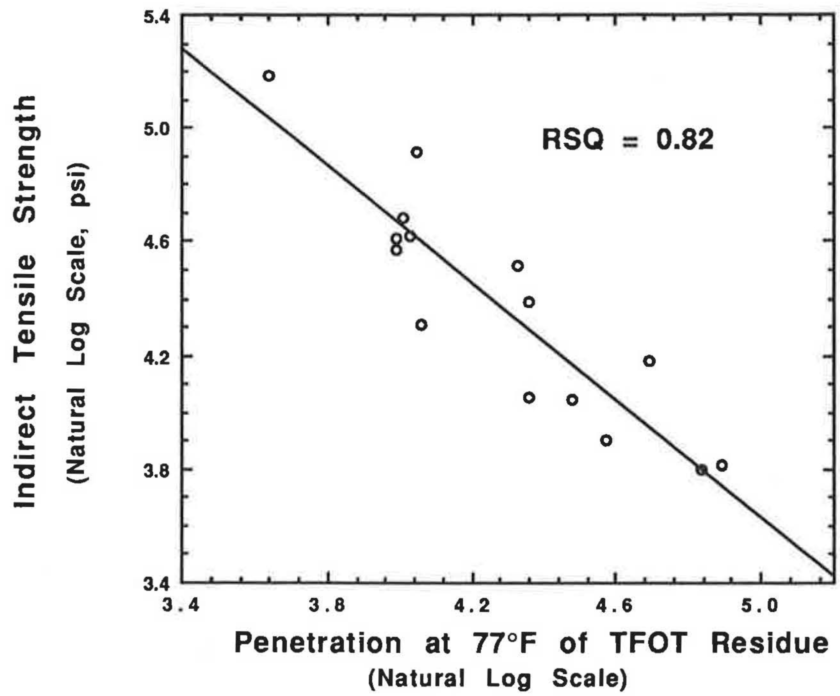

FIGURE 6 IDTS versus penetration (at 77°F) of the TFOT residue: gravel mix, 8 percent voids, 4.8 percent AC.

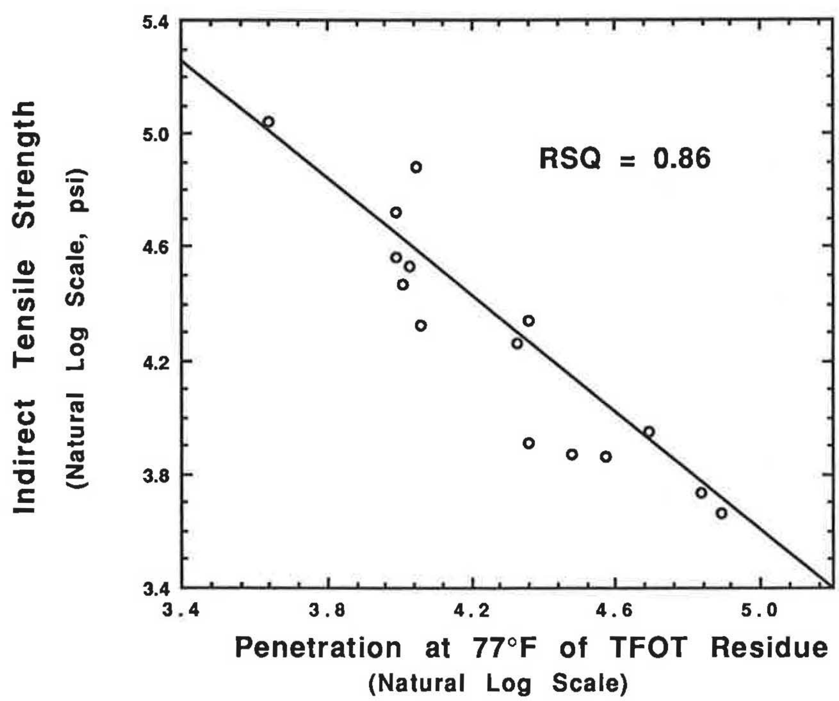

FIGURE 7 IDTS versus penetration (at 77°F) of the TFOT residue: gravel mix, 8 percent voids, 5.5 percent AC.

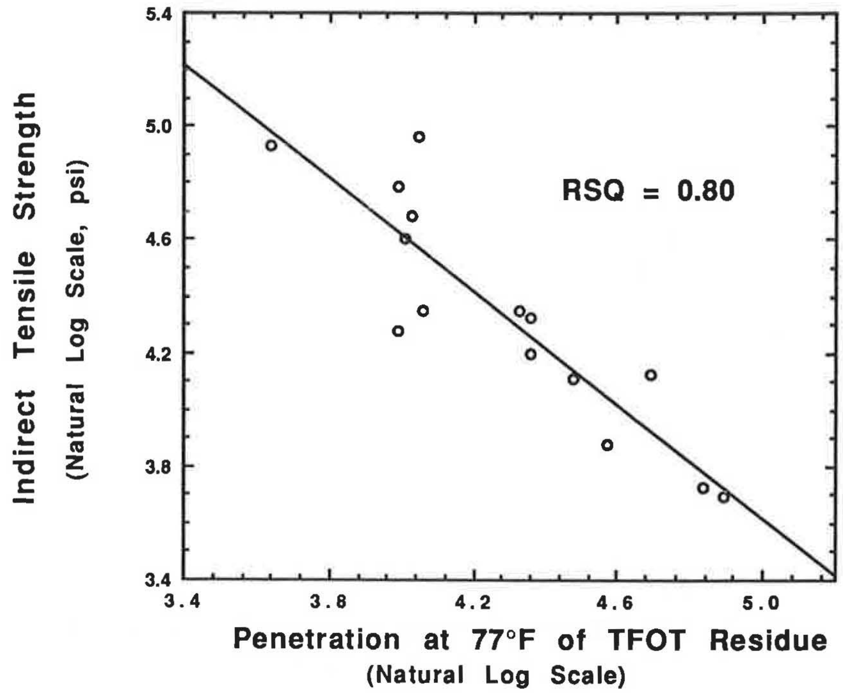

FIGURE 8 IDTS versus penetration (at 77°F) of the TFOT residue: gravel mix, 6 percent voids, 4.8 percent AC.

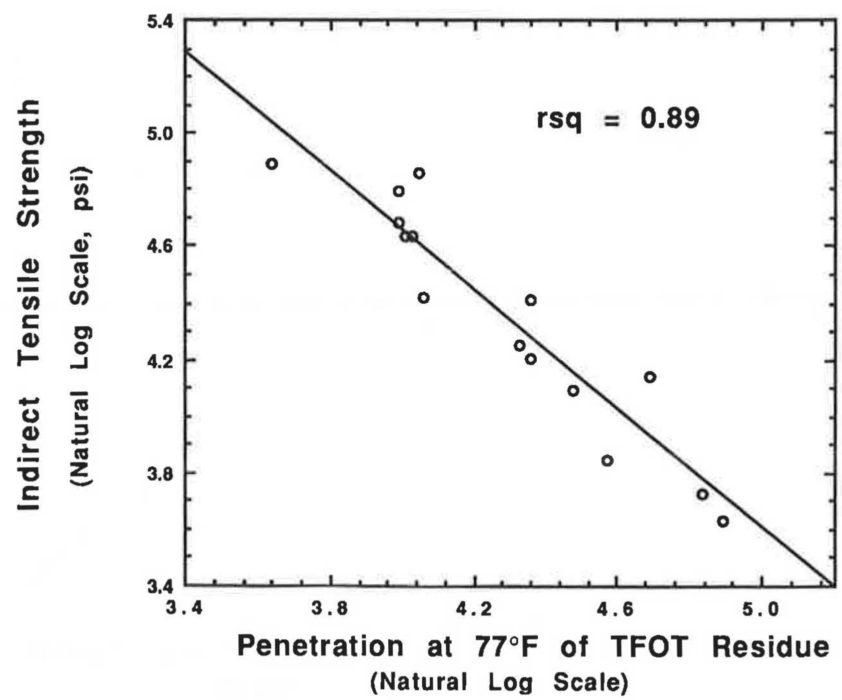

FIGURE 9 IDTS versus penetration (at 77°F) of the TFOT residue: gravel mix, 6 percent voids, 5.5 percent AC.

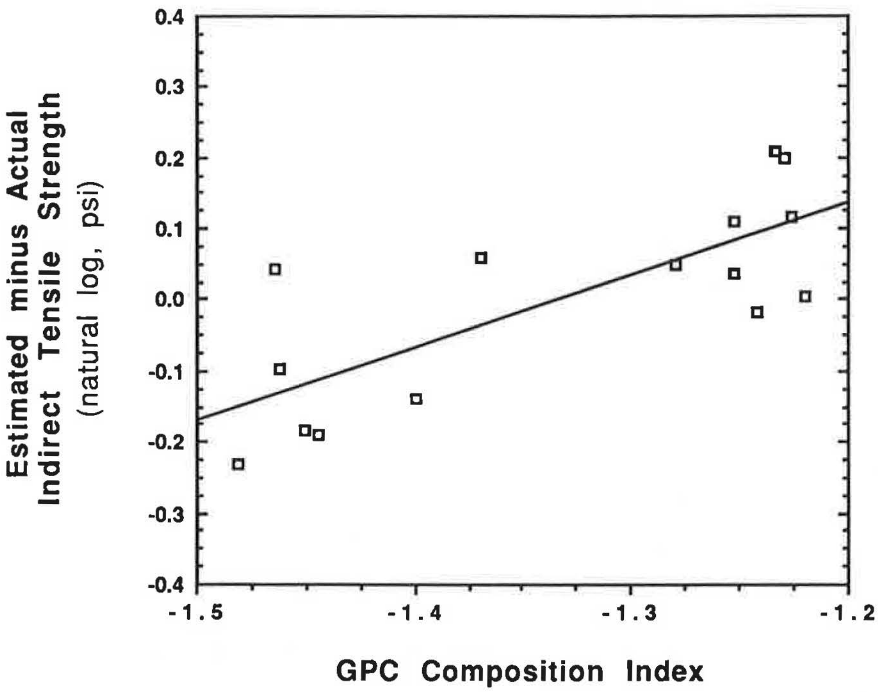

FIGURE 10 Effect of composition on IDTS: traprock mix, 8 percent voids, 4.8 percent AC.

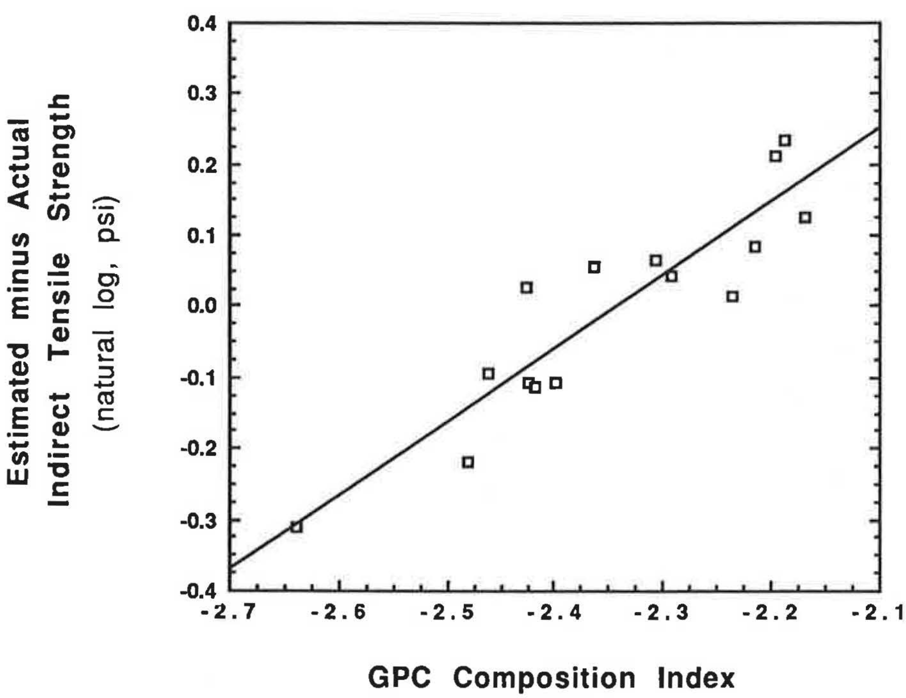

FIGURE 11 Effect of composition on IDTS: traprock mix, 8 percent voids, 5.5 percent AC.

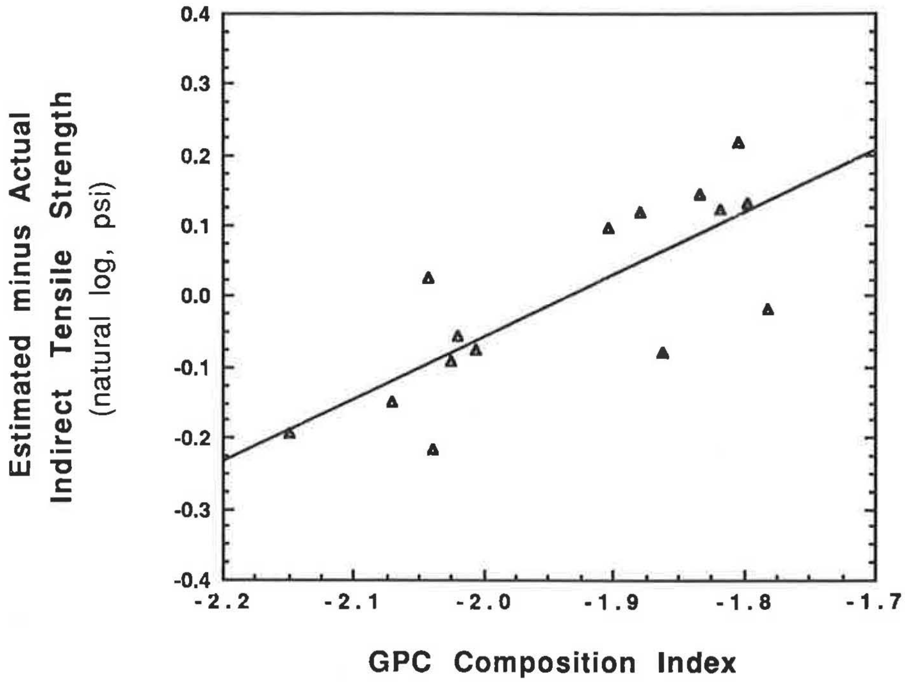

FIGURE 12 Effect of composition on IDTS: traprock mix, 6 percent voids, 4.8 percent AC.

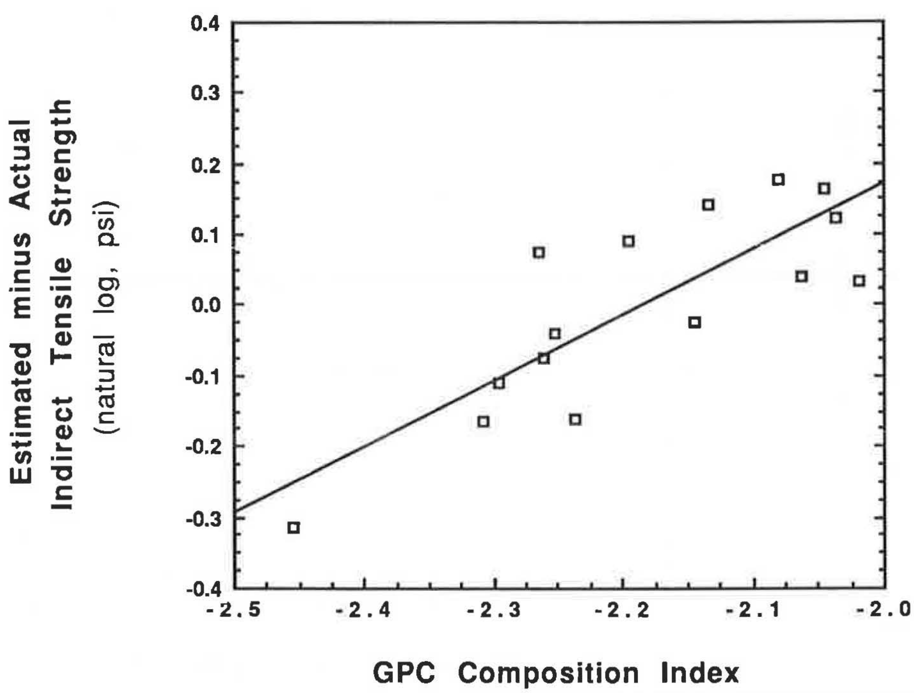

FIGURE 13 Effect of composition on IDTS: traprock mix, 6 percent voids, 5.5 percent AC.

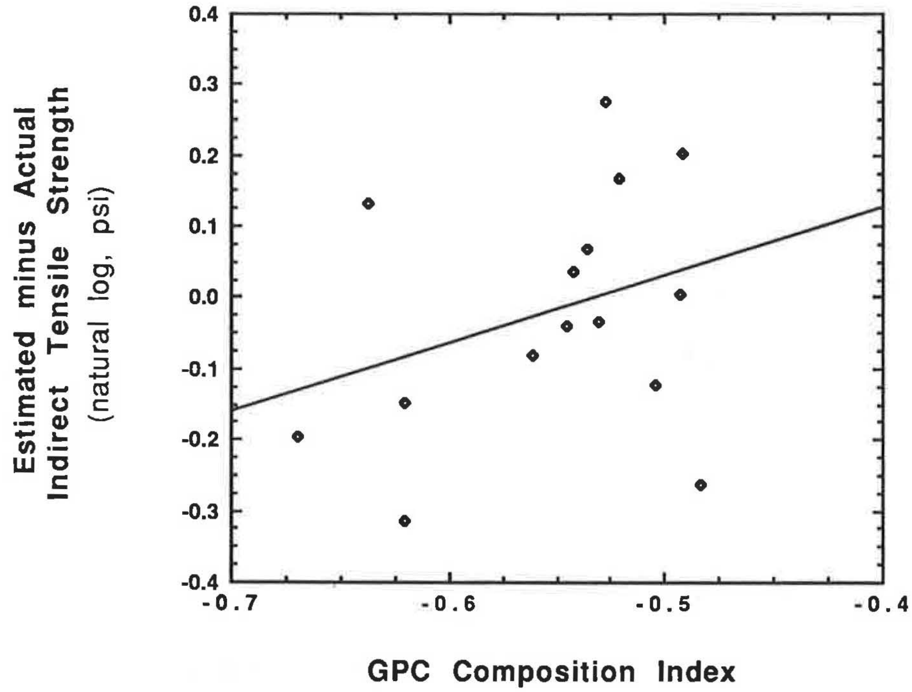

FIGURE 14 Effect of composition on IDTS: gravel mix, 8 percent voids, 4.8 percent AC.

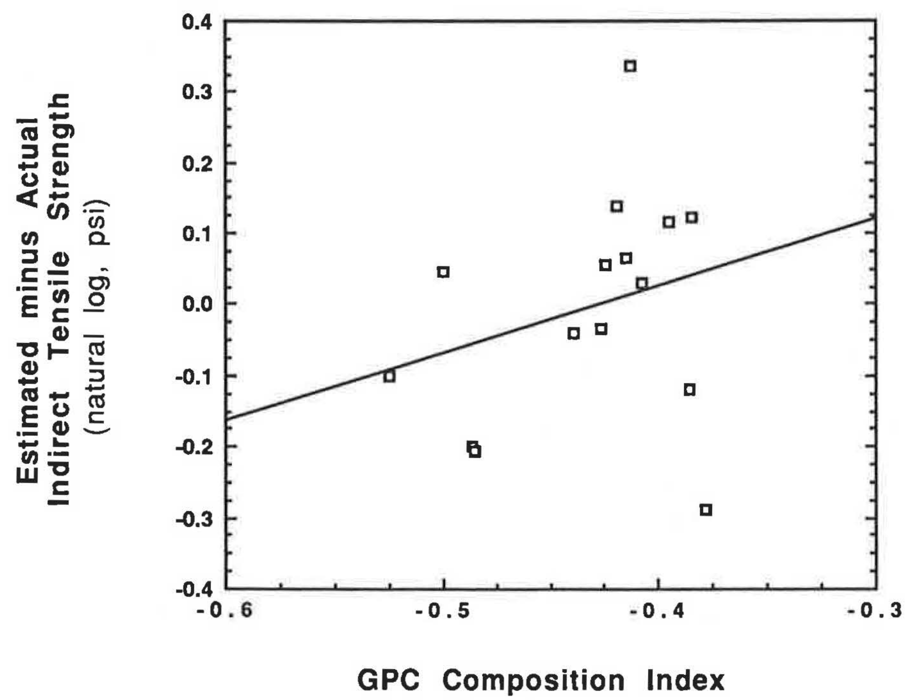

FIGURE 15 Effect of composition on IDTS: gravel mix, 8 percent voids, 5.5 percent AC.

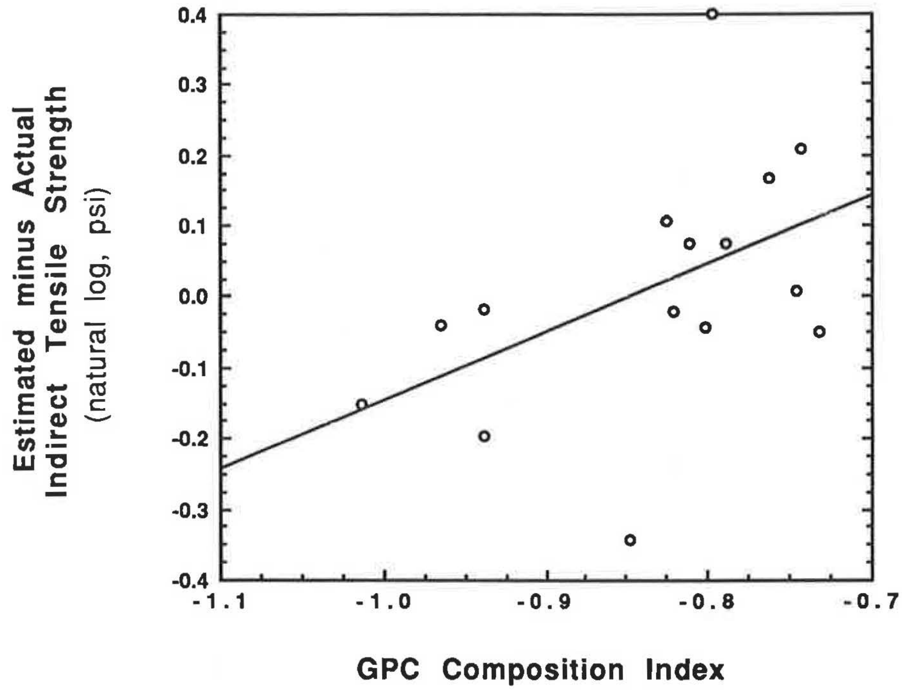

FIGURE 16 Effect of composition on IDTS: gravel mix, 6 percent voids, 4.8 percent AC.

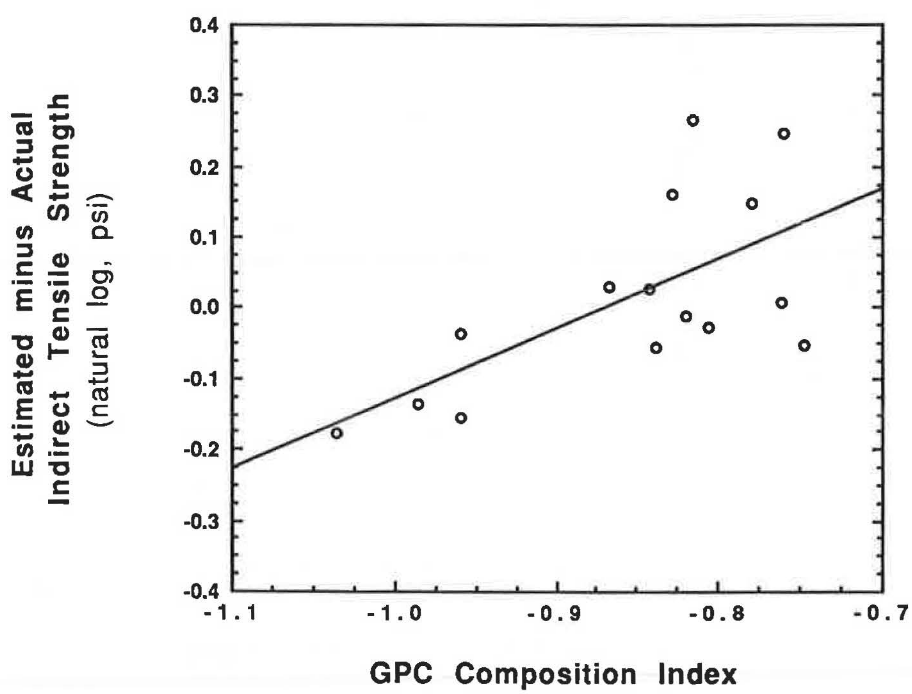

FIGURE 17 Effect of composition on IDTS: gravel mix, 6 percent voids, 5.5 percent AC.

SUMMARY

The effects of asphalt properties on the IDTS of a mix were examined. A strong correlation was observed between penetration of the TFOT residue and IDTS. The IDTS increases as penetration decreases.

The slope of the relationship between penetration and tensile strength varies significantly with aggregate type. The data suggest that the gravel mixes are more susceptible to temperature changes (in IDTS values) than the traprock mixes.

Aggregate type was also found to have a significant effect on the magnitude of the IDTS value of a given type of mix. In general, gravel mixes have higher tensile strength than equivalent traprock mixes with the same asphalt. However, the differences between two types of mixes with the same asphalt varied from asphalt to asphalt.

Asphalt composition was another factor that appeared to play a role in determining the IDTS of some mixes. For the traprock mixes, asphalt composition may account for differences of up to 55 percent in the IDTS. The effect of asphalt composition on gravel mixes was generally much less pronounced.

Overall, the IDTS of a given mix is clearly related to the consistency and composition of the asphalt. GPC is an effective method for characterizing the effects of asphalt composition on tensile strength.

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