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EVALUATION OF LOW TEMPERATURE PROPERTIES OF TYPICAL NDOT MIXTURES

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16. Abstract

The analysis of laboratory data from ten typical Nevada mixtures showed the following: There was no apparent relationships among the resilient modulus at 70° F and indirect tensile strengths at 0° F and 34°F for the ten mixtures evaluated in the program. The results of the indirect tensile strength test indicated that the strengths of all mixtures were similar. This fact was strongly disputed by the results of the resilient modulus tests. The low temperature cracking performances of the selected contacts were very similar. The reason for this uniform performance of all sections was the low frequency of low temperature cracking (one full crack per section) which failed to differentiate among the various mixtures.

Based on the analysis of the laboratory testing data, it could be concluded that the indirect tensile strength test was ineffective in evaluating the low temperature properties of typical Nevada mixtures. The test was not sensitive enough to evaluate individual mixtures. The test was quick and easy and obtained a broad indication of the low temperature properties of mixtures. However, the indirect tensile strength test should not be used to rigorously evaluate specific types of mixtures and rate their potential performance. NDOT should consider using the resilient modulus testing at low temperature (34°F) to evaluate the low temperature properties of asphalt concrete mixtures.

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INTRODUCTION

The low temperature cracking of asphalt concrete pavements has been a serious concern to pavement/materials engineers for many years.(1) It generally takes the form of transverse cracks which are nearly straight cracks across the pavement or perpendicular to the direction of traffic. This type of cracks are usually referred to as Non-load associated cracking. In reality, the true cause of low-temperature cracking of flexible pavements is a combined affect of both traffic and low temperature stresses. As the inservice pavement section is subjected to the temperature gradient which generates thermal stresses due to the thermal coefficient of the asphalt concrete material, traffic stresses are also induced. Since both of these stresses act in the tensile mode, they are always additive. Therefore, the total instantaneous tensile stress within the asphalt concrete layer, is the sum of the low temperature and traffic loading stresses.

There are two mechanism by which low-temperature cracking of pavements may occur; 1) fracture temperature and 2) thermal fatigue cracking. The fracture temperature mechanism is where the pavement temperature drops to a certain value at which the total tensile stress exceeds the tensile strength of the asphalt concrete material. The second mechanism is defined to be caused by thermal fatigue distress due to daily temperature cycling, which eventually exceeds the fatigue resistance of the asphalt concrete.(2)

Despite the great concern over low temperature cracking of pavements, there has not been a highly active research program on this topic. The limited research efforts consisted of developing various laboratory testing techniques to evaluate the low temperature cracking potential of asphalt concrete mixtures and few theoretical analysis models to estimate the performance of inservice pavements (3,4,5,6). The most recent research effort on low temperature cracking is represented by the Strategic Highway Research Program (SHRP) activities. The SHRP project A003A, "Performance Related Testing and Measuring of Asphalt-Aggregate Interactions and Mixtures", is currently evaluating various low temperature laboratory testing systems. The SHRP project, A005, "Development of Pavement Performance Models", is incorporating the low temperature cracking into the overall performance model of flexible pavements.

The environmental conditions in Nevada indicate that the pavements on the state highway system may potentially be subjected to both mechanisms of low temperature cracking. Pavements in districts 2 and 3 can be subjected to both extreme low temperatures and cycling over a low temperature range. Therefore, the low temperature properties of the asphalt concrete mixtures used on Nevada's highways must be known in order to estimate the performance of inservice pavements. The indirect tensile strength testing system at temperatures of 0^{o}F and 34^{o}F have been selected as the laboratory testing system to evaluate the Nevada mixtures.

SELECTION OF MIXTURES

Ten different mixtures, from projects constructed in 1987 and 1988, have been selected for the laboratory testing program. Projects in the range of 3 to 4 years old were selected in order to obtain the most PMS data possible. All ten mixtures are dense graded; eight mixtures are virgin materials and two mixtures include a certain percentage of recycled materials. Table 1 shows a summary of the data on the selected mixtures.

LABORATORY TESTING

The samples were collected from behind-the-paver mixtures by NDOT personnel and supplied to the University of Nevada, Reno materials laboratory for testing. A total of six replicate specimens of each mixture were compacted using the kneading compactor with a target air void content between 6 and 8 percent. In addition to the indirect tension test at $0^{\circ}F$ and $34^{\circ}F$, the resilient modulus at $77^{\circ}F$ was evaluated for all six replicates.

ANALYSIS OF DATA

The analysis of the laboratory data consisted of the following three stages:

- Repeatability of laboratory testing data
- Correlation among various mixture properties
- Correlation of mixture properties to PMS Data
- Low temperature stress calculations

Repeatability of Laboratory Testing Data

The mean, standard deviation, and coefficient of variation were evaluated for the resilient modulus at $77^{\circ}F$, indirect tension test at $0^{\circ}F$ and $34^{\circ}F$ data. Tables 2, 3, and 4 summarize the results of the repeatability study on resilient modulus and indirect tension tests, respectively. In general, all coefficients of variations were below 15 percent, except for the resilient modulus from contract number 2121 and the $34^{\circ}F$ indirect tension strength from contract number 2275. The results of the repeatability analysis showed that overall the resilient modulus and indirect tension tests are highly repeatable. Therefore, the data can be used in subsequent analysis where some relevant conclusions may be drawn.

Correlation Among Various Mixture Properties

As mentioned earlier, the resilient modulus at 77°F and the tensile strength at 0°F and 34°F were measured for each mixture. Figures 1, 2, and 3 show the relationship between the resilient modulus at 77°F and the tensile strength at 0°F, between the resilient modulus at 77°F and the tensile strength at 34°F, and between the tensile strengths at 0°F and 34°F, respectively. The data in the figures show that there is not any apparent relationship among the measured materials properties. Table 5 shows a summary of the test results with the contract number, asphalt grade, and tensile strengths at 0°F and 34°F. The data in Table 5 indicate that the asphalt grade effect on the tensile strengths at 0°F and 34°F is insignificant. However, this conclusion is not strongly supported since the size of the data base is very small.

Basically, the laboratory data have indicated that the low temperature tensile strengths of the tested mixtures are independent of the resilient modulus at 77°F and of the asphalt grade. In addition, the variation in the tensile strength among the various mixtures is very small. The means, standard deviations, and coefficients of variation of all of the mixtures at 0°F and 34°F are 11 and 10 percent, respectively (Table 6).

These values fall well within the coefficients of variation obtained from the laboratory repeatability analysis of individual mixtures (Tables 2 and 3). In addition, the average tensile strength values at 0°F and 34°F have very similar magnitudes.

In order to validate these observations, the resilient modulus laboratory test data at 77°F and 34°F were investigated. The resilient modulus data at 34°F were obtained from the original mix design data. Table 6 shows the mean, standard deviation and coefficient of variation of resilient modulus values for all mixtures. The resilient modulus data at both temperatures indicate that there are significant differences among the various mixtures contradicting the observations drawn on the basis of the indirect tensile strength test data.

Correlation of Mixture Properties to PMS Data

The results of the laboratory experiment have indicated that the low temperature tensile strengths of the various mixtures have similar magnitudes. Therefore, it may be hypothesized that the low temperature cracking performance of the inservice pavement sections constructed with these mixtures should be identical. The NDOT PMS data was extracted for the selected contracts in terms of the linear feet of transverse cracking, which is the primary indicator of low temperature cracking. Since some of the contracts were for access roads and ramps, the PMS data was available for a total of five contracts. Table 7 summarizes the transverse cracking data for the five contracts in terms of the number of feet of transverse cracking per a 100-foot section.

By looking at the data in Table 7 and recognizing the fact that the PMS data are collected by manual surveys which have a relatively large degree of inherent variability, it can be concluded that all of the sections performed comparably except for the section in contract 2275 on Route U.S. 50. This part of the contract has shown 150 feet of transverse cracking in the 100-foot section, which is considerably more cracking than on the other sections within the same contract. An additional investigation was carried out to identify the source of the problem by looking at the PMS data for the year prior to the construction of the roadway in contract 2275 on U.S. 50. It was discovered that the amount of transverse cracking in the previous year was 500 feet/100-foot section, which represents the maximum allowable input into the PMS data base. Therefore, the majority of the 150 feet of transverse cracking during the survey year of 1990 can be attributed to reflective cracking and not to low temperature transverse cracking.

In general, all of the sites have performed similarly under low temperature stresses. The uniformity in the low temperature performance of all the mixtures may be contributed to two probable causes: 1) All mixtures are indeed similar or 2) The magnitude of low temperature cracking is very low to a point that the differences in mixtures cannot be noticed. The first cause is strongly disputed by the resilient modulus test data at two temperatures. Considering the fact that the resilient modulus test is a more fundamental test, the credibility of the indirect tensile strength test in evaluating the low temperature properties of mixtures is very low. The second cause is more plausible since the average transverse cracking of all the sites is around 12 feet which translates into one full transverse crack per 100-foot pavement section.

Low Temperature Stresses

The most common method of predicting the low temperature cracking of inservice pavements is to evaluate the generated low temperature stresses within the pavement and compare them to the low temperature tensile strength of asphalt concrete material. Examples of this analysis are shown in Table 8. The tensile stresses are calculated from the following relationship:

$$\sigma_T = \alpha \times E \times \Delta T$$

where:

σ_T = tensile stress due to low temperature,

α = coefficient of thermal conductivity ~~activity~~ of the surface course, $\alpha = 1.35 \times 10^{-5}/^{\circ}F$,

ΔT = change in pavement temperature, ($^{\circ}F$) and

E = stiffness of asphalt concrete layer as a function of temperature and loading time.

The analysis assumes that the stress free temperature is equal to 75°F. The change in pavement temperature, ΔT, is a function of the depth within the asphalt concrete layer. For the purpose of this analysis, it was assumed that pavements in Nevada are subjected to air temperature range of 60°F below the 75°F stress free temperature which translates into minimum low temperature of 15°F. This condition is very representative of the environmental conditions of Districts 2 and 3. When selecting a representative value for the asphalt concrete stiffness, one must consider the combined effect of long loading time (i.e. 20,000 seconds) and the extremely low temperature. These two factors have opposite effects; the long loading time tends to produce low stiffness while the low temperature tend to produce high stiffness values of the asphalt concrete. In this analysis, stiffness values of 100, 400 and 1000 ksi were selected for the calculation of stresses. The 100 and 1000 ksi stiffness values represent the extreme and the 400 ksi represents the average expected value. The potential of low temperature cracking on the selected sites can be evaluated by comparing the estimated low temperature stresses in Table 8 with the average low temperature tensile strength values in Table 6. Based on the low temperature stresses and strengths, the asphalt concrete layer will crack only under special cases when the low temperature stiffness of the asphalt concrete layer is 1000 Ksi.

The only approach to determine the stiffness of asphalt concrete materials at a given temperature and loading time is by using the stiffness of the asphalt cement as follows:

$$Smix = S_{bit} [1 + \frac{2.5}{SN} (\frac{C_v}{1-C_v})]^{SN} \times 0.000145$$

Where:

Smix = stiffness modulus of the asphalt concrete mix (Psi)

S_{bit} = stiffness modulus of bitumen from Vander Poel's (7) monograph (N/m^2)

$$C_v = \frac{\text{volume of aggregate}}{\text{volume of aggregate + volume of bitumen}}$$

$$S_N = 0.83 \text{ long}_{10} [\frac{(4 \times 10^5)}{S_B}]$$

S_B = stiffness modulus of bitumen from Vander Poel's monograph (kg/m^2)

Using the above relationship with typical properties of AR 4000 and AR 8000 asphalt cement, the estimated low temperature stiffness of the mix at a loading time of 20,000 seconds is in the range of 100 to 400 ksi.

SUMMARY AND RECOMMENDATIONS

Based on the analysis of the laboratory data from ten typical Nevada mixtures, the following conclusions can be drawn:

- There are no apparent relationships among the resilient modulus at 77^oF and indirect tensile strengths at 0^oF and 34^oF for the ten mixtures evaluated in this program.
- The results of the indirect tensile strength test indicate that the strengths of all mixtures are similar. This fact was strongly disputed by the results of the resilient modulus tests.
- The low temperature cracking performances of the selected contracts are very similar. The reason for this uniform performance of all sections is the low frequency of low temperature cracking (one full crack per section) which fails to differentiate among the various mixtures.

Based on the analysis of the laboratory testing data, it can be concluded that the indirect tensile strength test is ineffective in evaluating the low temperature properties of typical Nevada mixtures. The test is not sensitive enough to evaluate individual mixtures. It is a quick and easy test to obtain a broad indication of the low temperature properties of mixtures. However, the indirect tensile strength test should not be used to rigorously evaluate specific types of mixtures and rate their potential performance. NDOT should consider using the resilient modulus testing at low temperatures (34°F) to evaluate the low temperature properties of asphalt concrete mixtures.

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Table 1. Characteristics of the selected projects

Contract Number	Year	Highway Number	Dist.	Mix Type	AC Grade	AC Source
2275	9-16-88	US 50	II	Type 2	AR8000	CONOCO
2216	9-01-87	Access Rd	II	Type 2	AR4000	Shell
2191	7-09-87	US 95	I	Recycl	AR8000 RAE-75	Witco
2225	9-01-87	US 93	III	---	---	---
2135	5-11-87	US 395	II	Type 2	AR8000	Witco
2121	11-10-87	I-580	II	Type 2	AR4000	Shell
2209(OM-44-88)	6-1-88	US 95	II	---	AR8000	---
OM-147-87(2191)	---	US 95	I	Recycl	---	---
OM-3-89	---	---	---	---	---	---
2209(OM-71-88)	5-1-88	US 95	II	---	AR8000	---

Table 2: Resilient modulus (77°F) test results

Contract Number	Sample Size	Average Resilient Modulus 77oF (ksi)	Standard Deviation	Coefficient of Variation (%)
2275	6	452	46	10.2
2216	6	652	45	6.9
2191	6	1376	190	13.8
2225	4	818	63	7.7
2135	6	1738	249	14.3
2121	6	1150	265	23.0
2209 (OM-44-88)	5	860	106	12.3
OM-147-87	4	912	62	6.8
OM-3-89	6	700	40	5.7
2209 (OM-71-88)	3	589	70	11.9

Average Coefficient of Variation = 11.3

Table 3: Indirect tensile strength (34°F) test results

Contract Number	Sample Size	Average Tensile Strength 77oF (psi)	Standard Deviation	Coefficient of Variation (%)
2275	3	285	76	26.7
2216	3	278	30	10.8
2191	3	343	34	9.9
2225	2	114	13	11.4
2135	3	315	21	6.7
2121	3	266	23	8.6
2209 (OM-44-88)	3	269	24	8.9
OM-147-87	2	352	13	3.7
OM-3-89	3	307	9	2.9
2209 (OM-71-88)	0			

Average Coefficient of Variation = 10.0

Table 4: Indirect tensile strength ($0^{\circ}F$) test results

Contract Number	Sample Size	Average Tensile Strength $0^{\circ}F$ (psi)	Standard Deviation	Coefficient of Variation (%)
2275	3	322	50	15.5
2216	3	331	36	10.9
2191	3	316	33	10.4
2225	2	292	6	2.1
2135	3	313	30	9.6
2121	3	296	12	4.1
2209 (OM-44-88)	2	280	30	10.7
OM-147-87	2	330	33	10.0
OM-3-89	3	406	5	1.2
2209 (OM-71-88)	3	294	34	11.6

Average Coefficient of Variation = 8.6

Table 5. Asphalt grades and tensile strengths of the various mixtures

Contract Number	Asphalt Grade	Tensile Strength at 0°F (psi)	Tensile Strength at 34°F (psi)
2275	AR8000	322	285
2191	AR8000	316	343
2135	AR8000	313	315
2209(OM-44-88)	AR8000	280	269
2209(OM-71-88)	AR8000	294	---
2216	AR4000	331	278
2121	AR4000	296	266
OM-147-87	---	330	352
OM-3-89	---	406	307

Table 6. The overall average, standard deviation, and coefficient of variation for all mixtures combined

Type of Test	Test Temperature	Average (psi)	Standard Deviation	Coefficient of Variation (%)
Indirect Tensile Strength	0°F	318	35	11
	34°F	302	33	10
Resilient Modulus	34°F	3,125,000	1,183,000	38
	77°F	925,000	393,000	42

Table 7. Summary of transverse cracking based on the PMS data

Contract Number	Route Number	Date of Construction	Year of Survey	Transverse Cracking (ft/100-ft Section)
2275	SR 844	9-16-88	1989	9
			1990	27
	SR 361	9-16-88	1989	26
			1990	30
	US 50	9-16-88	1990	150
2191	US 91	7-09-87	1990	13
2225	US 93	9-01-87	1990	12
2135	US 395	5-11-87	1990	17
2209	US 95	6-01-88	1989	12
				12

Table 8. Calculated change in pavement temeprature and temperature stresses for daily air temperature range below stress free temperature = 60°F

Depth Below Surface (in)	Change in Pavement Temperature, ΔT (°F)	Temperature Stresses σ_T		
		E_{AC} = 100,000	E_{AC} = 400,000	E_{AC} = 1,000,000
0	50	68	272	680
0.5	48	65	260	650
1.0	46	62	248	620
1.5	45	61	244	610
2.0	43	58	232	580
2.5	42	57	228	570
3.0	41	55	220	550
3.5	40	54	216	540
4.0	39	53	212	530
4.5	38	51	204	510
5.0	37	50	200	500
5.5	36	49	196	490
6.0	36	49	196	490
6.5	33	45	180	450
7.0	31	42	168	420
7.5	29	39	156	390
8.0	27	36	144	360

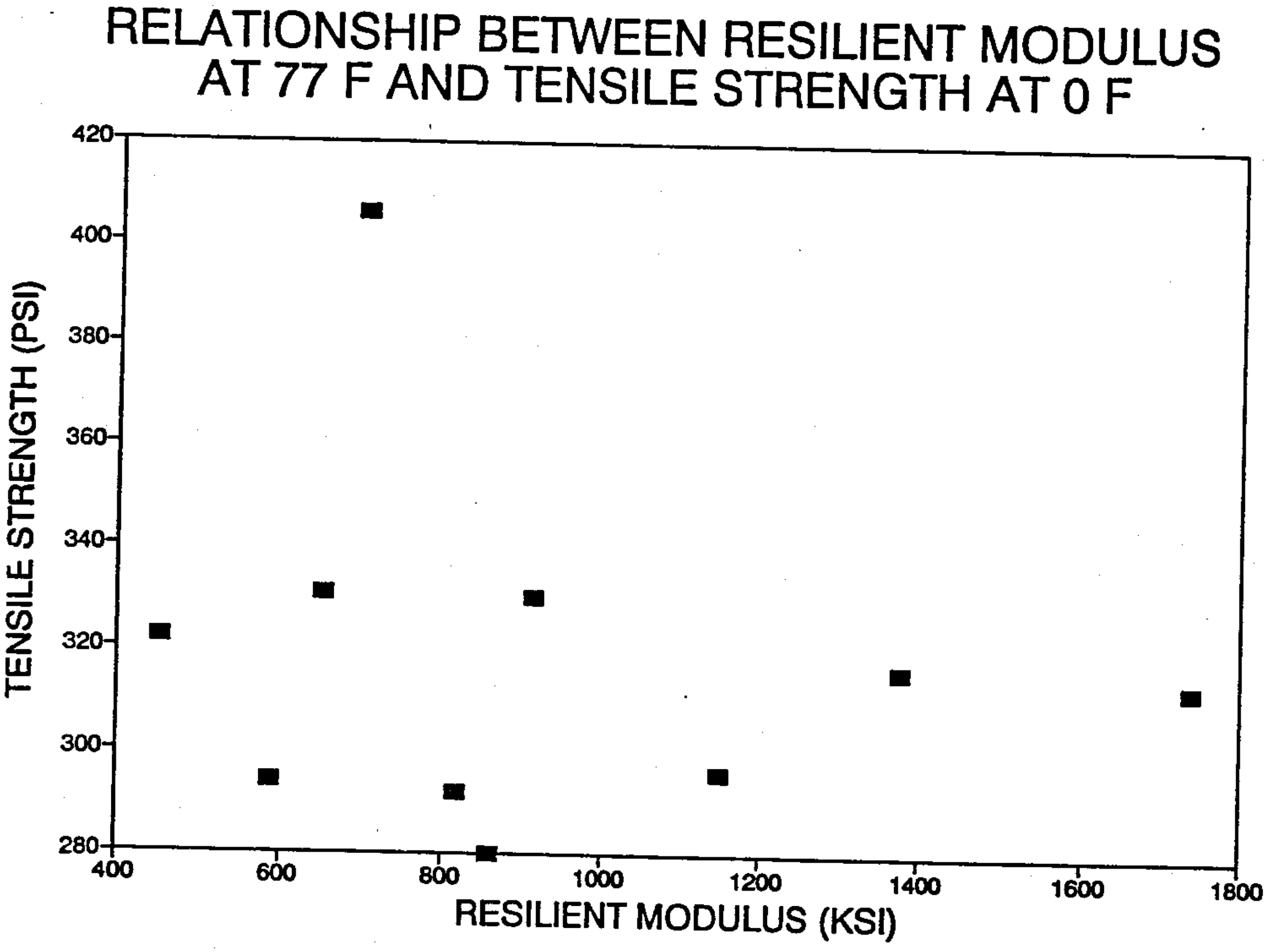

Figure 1. Relationship Between Resilient Modulus at 77°F and Tensile Strength at 0°F for all mixtures

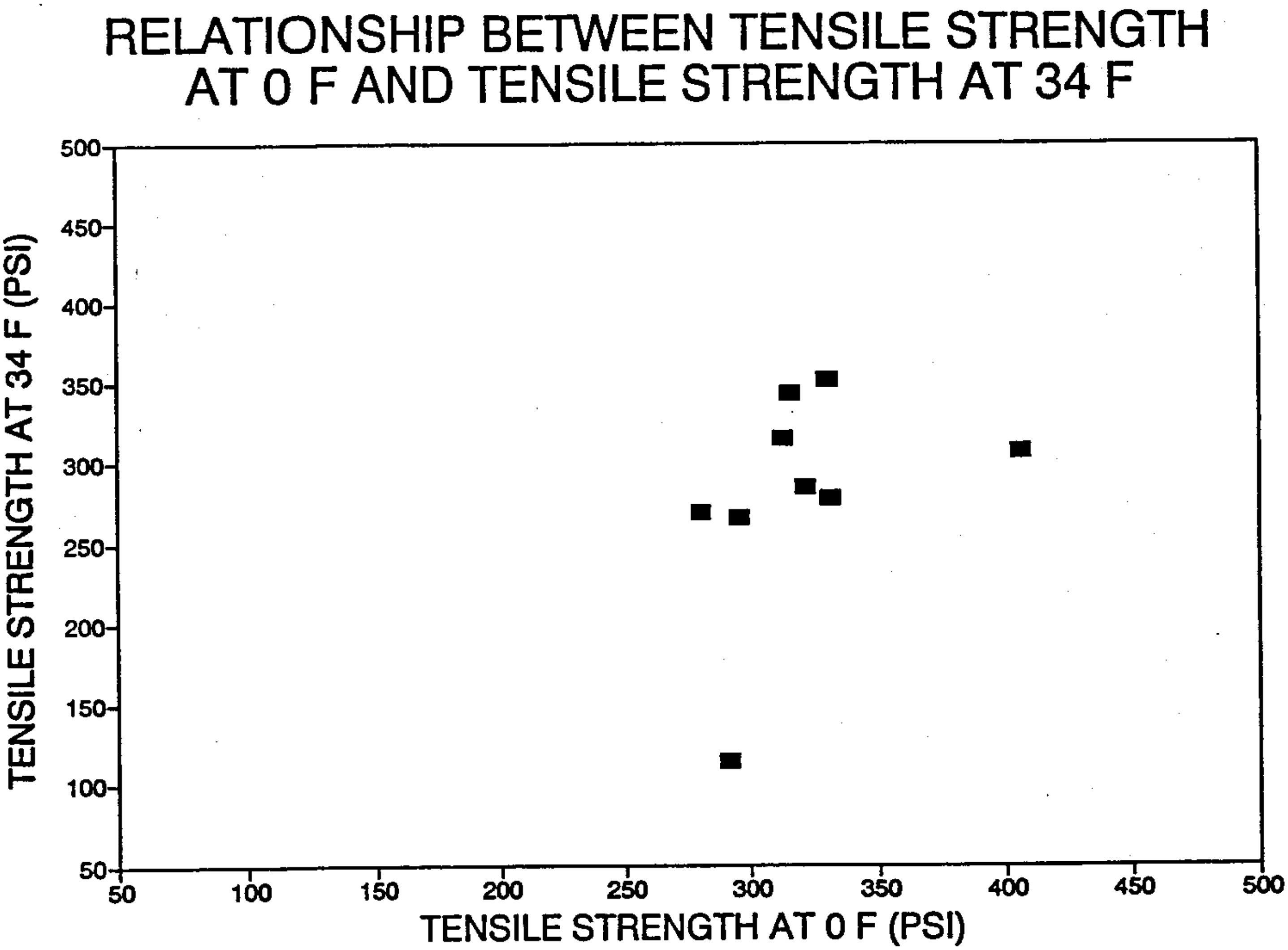

Figure 3. Relationship Between Tensile Strength at 0°F and Tensile Strength at 34°F for All Mixtures

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