Tensile Strength of Asphalt Films and Road Life

A. W. SISKO, American Oil Company, Whiting, Indiana

The tensile strength of thin films of 12 asphalts in different conditions of aging—unaged, aged in the thin film oven test, and aged in roads for up to eleven years—increased by as much as 140 percent as the temperature decreased from 80 to 0 F. Experimental conditions insured failure by brittle fracture. At low temperatures, TFOT aging produced no significant differences in the tensile strength of the asphalts but road aging produced large differences. The tensile strength of road-aged asphalts appears unrelated to asphalt source or composition.

• ASPHALT roads can crack under the tensile stresses produced by traffic, by changes in the subgrade, and by thermally induced expansions and contractions. Road life can therefore be expected to depend on how long the thin asphalt films in the road can resist tensile rupture. Nonetheless, little or no work has been done to determine how aging affects the tensile strength of asphalt in a road. Part of the difficulty has been the lack of samples that would permit significant correlation studies.

Tensile tests on asphalt concrete have shown that the locus of failure moves from within the film of asphalt between the stones to the asphalt-stone interface, and finally the stones fracture as the rate of loading is increased or the temperature is decreased (1). Since such tests do not clearly indicate the fracture properties of the thin, 5- to 15-micron, asphalt films themselves, alternative procedures have been developed to test the strength of thin films held between metal surfaces. A study of the variables in the latter test showed that the mode of failure of the films changes from ductile flow, through a mixed region, to brittle fracture with a decrease in temperature, a decrease in film thickness, and an increase in rate of extension, and that the strength of a film increases in the transition from the ductile to the brittle state (2). However, that study was made with a single, unaged asphalt and did not extend to temperatures low enough to reveal the maximum that must exist in the tensile strength of asphalt.

Twelve aged asphalts became available in the course of an investigation of the dynamic mechanical properties of asphalts in relation to road durability (3). Eleven came from the 1954-1955 survey of the Bureau of Public Roads (4, 5) and had been used to make roads which are 11 years old. The twelfth came from a 3-year-old road in Illinois. The roads are well distributed around the country and the condition of each was evaluated, using a standard rating form, by state highway personnel. The asphalts represented a variety of crude sources and manufacturing processes.

The tensile strength of the asphalt was determined at three stages of aging—unaged, aged in the thin film oven test (TFOT) (6), and aged in the road. The TFOT was run to reproduce approximately the condition of the asphalt in the new road after the hot plant mixing and laying operations.

It would not be unexpected if the extent of cracking in the roads did not correlate with the asphalt tensile strength. The roads were not uniformly made and therefore the thicknesses and moduli of the stone layers and the asphalt concrete layers varied from one road to another. Furthermore, the strain in the asphalt film depends on other factors such as the film thickness, the interlock between the stones, and the ambient temperature. Nevertheless, if the contribution of asphalt tensile strength to road life is to be determined, the earlier work (2) must be extended to include more asphalts and several

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TABLE 1

PROPERTIES AND CHARACTERISTICS OF ASPHALT SAMPLES

Asphalt	BPR No.[a]	Location	Process[b]	Crude Source	Penetration at 77 F			Viscosity at 140 F, Kilopoises		
					Unaged	TFOT	Road	Unaged	TFOT	Road
1	92	California	V, S	California	89	47	29	1.41	3.70	25.0
2	39	Kentucky	—	—	88	51	18	1.66	4.74	114.0
3	—	Illinois	—	Midcontinent	78	46	38	1.46	4.80	9.4
4	19	Maryland	V	Venezuela	91	53	17	1.92	5.54	96.0
5	9	Massachusetts	V	Venezuela and Texas	91	51	22	1.82	5.08	16.0
6	62	Nebraska	V, P, B	Kansas, Oklahoma, Texas	85	55	57	1.61	4.58	5.0
7	71	Oklahoma	V, P, B	Midcontinent	82	54	46	1.62	2.72	3.9
8	97	Oregon	V, S	California	94	36	29	1.25	6.27	11.0
9	25	Tennessee	S	Venezuela and Mexico	85	51	24	3.00	11.10	390.0
10	74	Texas	V, P, O	Texas	93	64	28	1.16	2.12	29.0
11	185	Wisconsin	V, B, S	Midcontinent	78	48	28	1.47	3.29	43.0
12	114	Wyoming	V	Wyoming	94	54	48	1.27	3.37	2.4

[a] See references 4 and 5.

[b] Process codes: V = vacuum distillation; P = propane fractionation; B = blending different asphalt grades; O = blowing (oxidation); S = steam distillation.

conditions of aging, among them road aging. The data may provide a valuable background for future work.

EXPERIMENTAL

Samples

Table 1 gives the properties and characteristics of the asphalt samples. Eight crude sources and five processes are represented. Compared with the unaged samples, the viscosity of the TFOT samples increased by no more than a factor of five, indicating that the asphalts are representative of those currently being manufactured. The viscosity of the road asphalts is the average obtained with two samples extracted from different sections of the same pavement.

Table 2 gives the asphalt compositions determined by a combined solubility and chromatographic procedure.. The asphaltenes were separated by insolubility in n-hexane. To obtain hard resins, soft resins, and oils, the asphalt was adsorbed on alumina and washed successively with n-hexane and ether. Asphaltenes varied from a low of 1 percent for the unaged Sample 10 (Texas) to a high of 37 percent for Sample 9 (Tennessee) extracted from the road. In general, asphaltenes increased with aging, hard

TABLE 2

ASPHALT COMPOSITION

Component[a]	Location	Unaged	TFOT	Road	Location	Unaged	TFOT	Road
A	California	15	19	24	Oklahoma	8	10	12
HR		28	25	30		26	27	32
SR		35	34	22		44	42	36
O		22	22	24		22	21	20
A	Kentucky	12	15	24	Oregon	15	20	21
HR		20	19	28		28	26	29
SR		40	39	24		30	28	26
O		28	27	24		27	26	24
A	Illinois	16	20	22	Tennessee	23	26	37
HR		20	20	24		18	19	18
SR		37	34	29		39	37	26
O		27	26	25		20	18	19
A	Maryland	19	22	24	Texas	1	1	3
HR		19	18	27		38	39	52
SR		36	35	29		41	40	26
O		26	25	20		20	20	19
A	Massachusetts	15	19	28	Wisconsin	14	16	26
HR		22	19	26		23	25	25
SR		38	39	27		39	38	26
O		25	23	19		24	21	23
A	Nebraska	11	14	15	Wyoming	15	18	18
HR		24	22	24		20	21	23
SR		39	38	35		43	40	35
O		26	26	26		22	21	24

[a] Component codes: A = asphaltenes, HR = hard resins, SR = soft resins, O = oils.

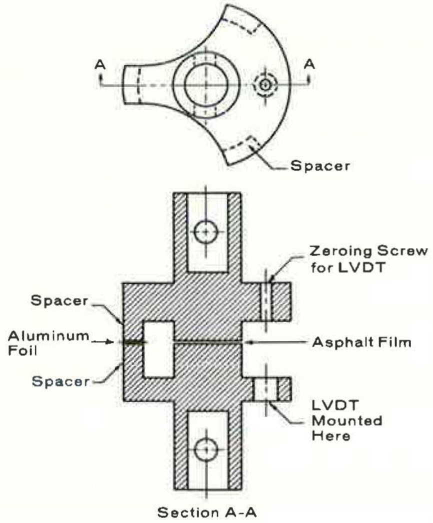

Figure 1. Sectional view of holder.

TABLE 3

EVALUATION OF ROAD CONDITION

Location	Cracking	Plastic Deformation	Ride[a]
California	Moderate	None	3.5
Kentucky	Large	Slight	3.5*
Illinois	None	None	4.0
Maryland	Large	Slight	3.5*
Massachusetts	Large	None	3.5
Nebraska	Slight	Moderate	3.5
Oklahoma	None	Moderate	3.7
Oregon	Slight	None	4.0
Tennessee	Slight	Severe	2.5
Texas	None	None	3.5
Wisconsin	Moderate	None	2.2*
Wyoming	Slight	Slight	3.0

[a] Ride Evaluation: 4-5 very good, 3-4 good, 2-3 fair, 1-2 poor, 0-1 very poor.

*Road in need of service.

resins increased or remained about the same, soft resins decreased, and oil decreased or remained about the same.

Highway personnel in each state walked and rode over the sampled roads to evaluate the extent of cracking, the amount of plastic deformation, and the riding quality. Table 3 gives a qualitative summary of these findings.

Equipment and Procedure

All tensile tests were performed on 0.0005-in. (13-micron) asphalt films in an Instron tester operated at an extension rate of 0.1 in./min. These conditions were selected to cause failure by brittle fracture.

The films were prepared between aluminum holders designed to produce a uniform film thickness by means of spacer legs ground and lapped to be coplanar with the surface of the holder in contact with the asphalt film. Figure 1 shows how spacers of aluminum foil are used to produce uniform films. The holders also provide a mounting for a Daytronic Model 103A-80 linear variable differential transformer (LVDT) extensometer. The Instron was equipped with an evironment control chamber and with ball-and-socket joints similar to those used by Majidzadeh and Herrin (2).

Attempts to use holders with stone faces in contact with the film were unsuccessful. These holders were difficult to manufacture, and, at low temperatures, fracture occurred sometimes in the asphalt and sometimes in the stone.

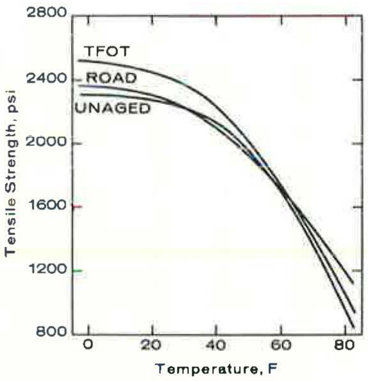

Figure 2. Dependence of tensile strength on temperature.

To prepare a film, a small quantity of asphalt was spread on one of two holders that had been preheated to 250 F in an oven. Small squares of foil were quickly positioned on the spacer arms and the holders were clamped together in the position shown in Figure 1 with a C-clamp across each of the spacer arms. Four sets of holders were made up and each test was run in quadruplicate. The loaded holders were cooled for 30 minutes at room temperature and finally were held for an additional 30 minutes in the Instron chamber at the selected test temperature before testing.

Just before testing, the LVDT was attached and zeroed with the zeroing screw. Finally, the C-clamps were removed and the Instron tester started. The Instron recorder gave the breaking force and the carrier amplifier indicator of the LVDT gave the extension at break.

TABLE 4

TENSILE STRENGTH OF ASPHALT FILMS

(in psi)

Asphalt	Unaged			TFOT					Road		
	0 F	40 F	80 F	0 F	20 F	40 F	60 F	80 F	0 F	40 F	80 F
1	1850	2110	970	2520	2570	2330	1640	1150	2430	2180	1760
2	2340	2040	840	2550	2340	2290	1530	930	2180	1860	1440
3	2300	1810	970	2410	2180	1960	1570	1070	2240	2100	1200
4	2440	2150	780	2430	2250	2270	1670	920	2510	2140	1480
5	2200	2020	970	2470	2200	2190	1680	1070	2090	1870	1440
6	2340	2040	790	2650	2390	2160	1540	970	2200	2010	1020
7	2010	2190	1030	2700	2570	2340	1730	1170	2230	2340	940
8	2550	2340	1060	2550	2670	2360	1920	1180	2840	2550	1170
9	2710	2080	1080	2610	2550	2360	1660	1210	2190	1710	900
10	2570	2040	810	2530	2950	2320	1530	880	2380	2240	1000
11	1820	1970	1020	2340	2140	2240	1590	1120	2470	2190	1060
12	2320	2160	810	2340	2480	2290	1670	970	2420	1990	1070
Average	2290	2080	930	2510	2440	2260	1640	1050	2350	2100	1210

Failure was always by brittle fracture. The stress-time recording was linear right up to the time of fracture and there was a sharp report at failure. The broken film was divided equally between the two surfaces. The fracture started at a small defect and propagated along the parabolic lines characteristic of the fracture surfaces of amorphous brittle materials. Because the area of the new surface could not be readily determined, the tensile strength was assigned on the basis of the initial area of the film.

RESULTS

The tensile strengths of the aged and unaged asphalts at temperatures from 0 to 80 F are given in Table 4. More temperatures were used in testing the TFOT asphalts in order to better establish how tensile strength changes with temperature. The data for the unaged and TFOT samples are averages of four determinations; those for the road samples are averages of eight determinations because two samples of asphalt concrete were supplied from each road. Statistical analysis was applied to determine objective criteria for the acceptability of individual determinations. Less than 1 percent

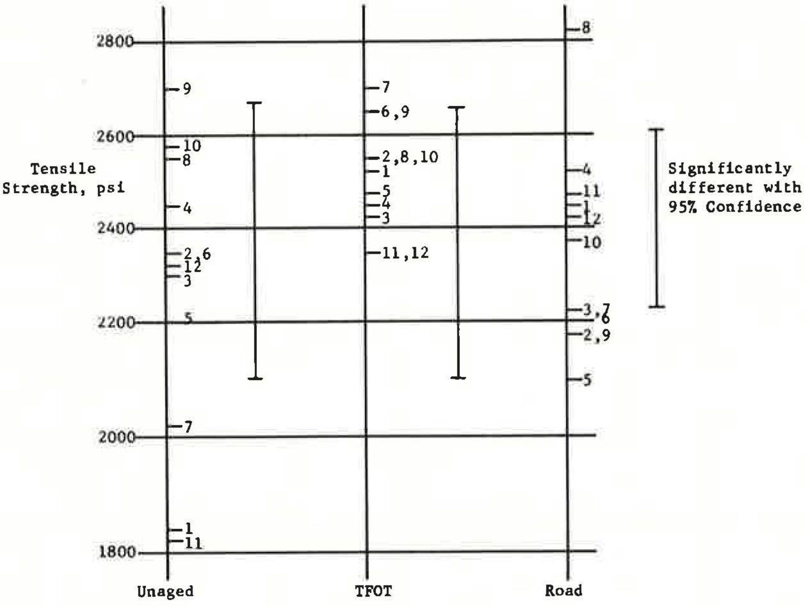

Figure 3A. Ranking of tensile strengths at 0 F.

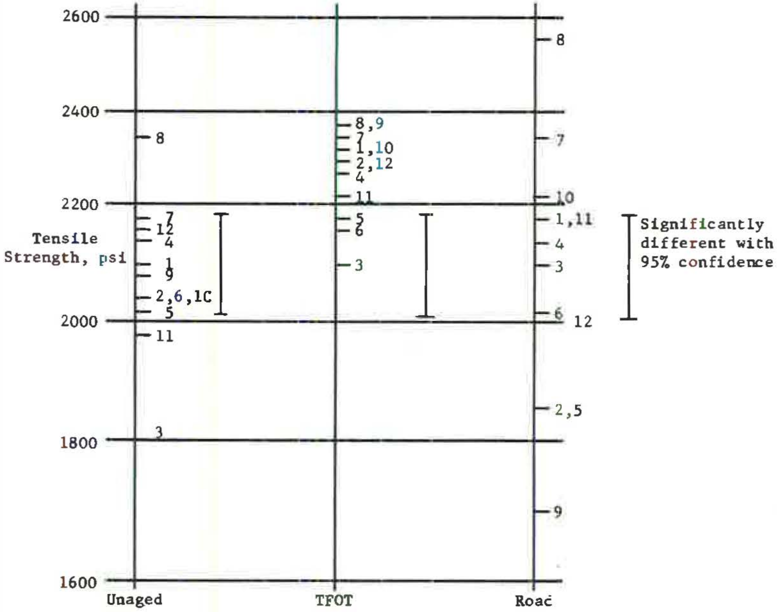

Figure 3B. Ranking of tensile strengths at 40 F.

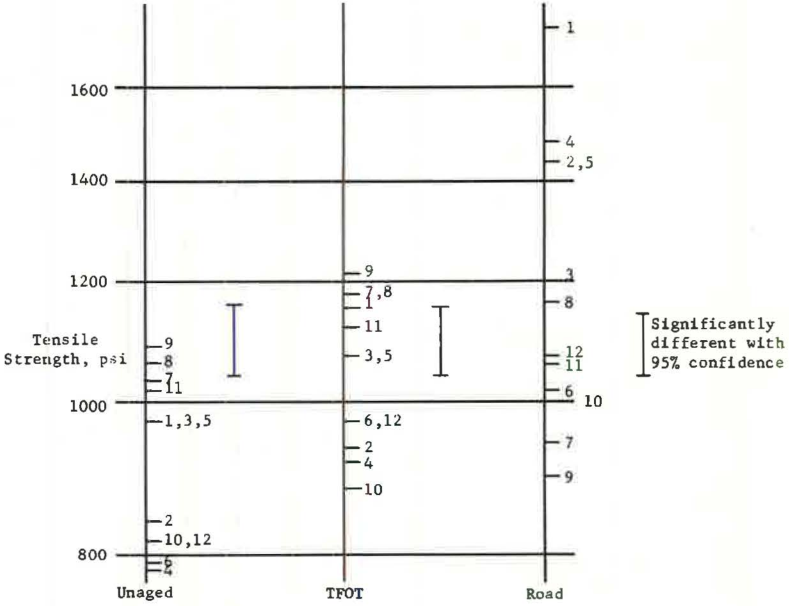

Figure 3C. Ranking of tensile strengths at 80 F.

of the data were rejected. Finally, the 95 percent confidence level for significant difference between samples was determined for 0, 40, and 80 F and for each condition of aging.

The general dependence of tensile strength on temperature is given by the averages in Table 4, which are also plotted in Figure 2. At 80 F the order of average tensile strengths is road >TFOT > unaged; at 60 F unaged and aged asphalts are about the same; and at 0 F the TFOT films are strongest with the unaged and road being about the same. A maximum tensile strength, averaging from 2300 to 2500 psi, was reached for all conditions of aging.

Figure 3 shows rankings of the asphalt samples according to tensile strength at 0, 40, and 80 F. The tensile strength scale is logarithmic so the 95 percent confidence level applies any place on the scale. At 0 F there are differences between the unaged and road asphalts, but there is no significant difference between the asphalts after the TFOT. The same is approximately true at 40 F; however, at 80 F there is a greater spread in the data.

Failure occurred at extensions of about 3×10^{-4} in. when the applied load was 2000 pounds. For the gage length involved, an extension of this order would be expected if the two holders were made as one piece with no asphalt film present (the tensile elastic modulus of aluminum is about 1×10^{7} psi). Whatever the tensile modulus of asphalt in thin films is, at a minimum it is within an order of magnitude of that of aluminum. Extension measurements were discontinued after establishing the relative closeness of the strain in the aluminum to the total strain.

Neither asphaltene nor resin content correlated with tensile strength. The interesting experiment that could be made by separating asphalt components with a preparative-type gel permeation chromatography column and determining the tensile strength of the components was not performed.

DISCUSSION AND CONCLUSIONS

Thin asphalt films, of about the thickness found in roads, increase in tensile strength with decrease in temperature to a maximum value which is about the same at low temperatures for all asphalts in newly constructed roads. Subsequent weathering develops appreciable differences in tensile strength between asphalts. The TFOT shows that there is no correlation between tensile strength and the source of the asphalt or its composition. Furthermore, the amount of cracking of the road does not appear to correlate with asphalt tensile strength. Changes in asphalt composition are not large enough to show the contribution that the individual components make to the tensile strength of asphalts. In addition, the failure of thin films is a complicated mixture of the strengths of cohesive and adhesive bonding.

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