TRENDS OF PAVEMENT CHARACTERISTICS DURING TWELVE MONTHS OF A DESIGNED EXPERIMENT

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This paper presents some of the significant findings observed during the first 12-month period of a comprehensive 2-year field and laboratory research project. Sixteen experimental sections were constructed as part of a primary highway project in Utah. The experiment consists of 5 factors at 2 levels, each incorporated in a one-half replicate of a 2^5 fractional factorial experiment. The 5 factors are thickness of surface course, thickness of base course, rubber solid content, asphalt viscosity, and asphalt content. Information presented in this paper includes the following tests performed at 3-month intervals: tests on physical properties of recovered asphalt, tests of strength properties of pavement mixture, and tests on the pavement properties. Results from the tests show much significance related to the 5 main factors of the experiment. These test results also indicate that many changes occurred in important pavement characteristics during the 12-month period. The information contained in this paper confirms that this statistically designed field and laboratory experiment is producing significant information about many of the properties of actual highway pavements during the first 12 months in service.

Information presented in this paper describes some of the significant findings observed during the first 12-month period of comprehensive 2-year field and laboratory experiments. The 16 test sections were constructed as part of a federal-aid primary highway project. Reports have been issued that describe the design, construction, and initial evaluation of the project (1, 2, 3, 4).

The overall purpose of this research project is to analyze, by means of a statistically designed experiment, the behavior and performance of bituminous pavements in which asphalts having different viscosities are modified with varying amounts of rubber solids and incorporated into bituminous mixes in amounts above and below the designed percentage and placed in different thicknesses on various depths of granular base.

The 5 factors included in the experiment are given in Table 1. An experiment with 5 factors at 2 levels, each designed as a complete factorial, would require $2^5 = 32$ test sections. However, by use of a fractional factorial design having only 16 test sections, it is possible to provide data to evaluate all the main effects—T, B, S, V, and C—and the ten 2-factor interactions—TB, TS, BS, CV, TV, BV, CS, SV, BC, and TC. In statistical terms the design comprises 16 test sections of a one-half replicate of a 2^5 fractional factorial experiment. There are 5 factors at 2 levels each and one of the factors, C, is confounded with the third order interaction. The levels of each factor in the test sections are given in Table 2.

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TABLE 1

FACTORS AND THEIR LEVELS INVOLVED IN THE EXPERIMENT

Symbol	Factors	Level	
		Low(-)	High(+)
S	Synthetic rubber solids	0 percent	3 percent
V	Viscosity, 85 to 100 penetration at 140 F	Low	High
C	Design percentage of asphalt	0.9C or 5.2 percent	1.1C or 6.4 percent
T	Design thickness of asphaltic concrete surface	0.5T or 3.0 in.	1.0T or 5.7 in.
B	Design thickness of untreated granular base course	0.5B or 2.2 in.	1.0B or 4.0 in.

The full pavement design was 6 in. of asphaltic concrete surface course and 4 in. of granular base course. The experimental pavement in sections having one-half this design thickness is expected to exhibit accelerated failures, thereby reducing the length of time to completion of the project. The highway consists of two 12-ft traffic lanes with 10-ft paved shoulders. The material compositions of 16 test sections are given in earlier reports (3, 4), and the test methods are given in Table 3.

ASPHALT PROPERTIES

Kinematic Viscosity

The kinematic viscosity at 140 F of the asphalt recovered from cores cut from the pavements was determined at 3-month intervals. Figure 1 shows the results obtained. The heavy solid line in the center shows the average overall trend of the 16 test sections during the first year. Above and below this line is the average plot of the high and low level of viscosity, V, rubber solids, S, and percentage of asphalt content, C. The results at each level are the averages of 8 test sections. For example, the +S plot shows the average change of kinematic viscosity at 140 F of the recovered asphalt for the 8 rubberized test sections. The -S plot shows the average kinematic viscosity of the recovered asphalt at 140 F for the 8 nonrubberized test sections. The following results are apparent:

1. The kinematic viscosity of the recovered asphalt steadily increased with time in the first 12 months. It increased from 3,082 to 5,260 stokes from directly after laydown to the 12-month period.

2. The 3 percent synthetic rubber solids increased the viscosity initially from 1,300 to 4,800 stokes. After 12 months in the pavement, there was still a large difference: -S = 3,000 and +S = 6,500 stokes.

3. Initially the high-viscosity asphalt, +V, was 1,248 stokes greater than the low viscosity, -V, and every period to 12 months still showed a similar large difference.

4. Percentage of asphalt content present in the misture showed no significant effect on kinematic viscosity at 140 F.

TABLE 2

LEVELS OF FACTORS CONTAINED IN EACH TEST SECTION

Test Section	Level				
	T	B	S	V	C
12	-	-	-	-	-
11	+	-	-	-	+
10	-	+	-	-	+
9	+	+	-	-	-
13	-	-	+	-	+
14	+	-	+	-	-
15	-	+	+	-	-
16	+	+	+	-	+
4	-	-	-	+	+
3	+	-	-	+	-
2	-	+	-	+	-
1	+	+	-	+	+
5	-	-	+	+	-
6	+	-	+	+	+
7	-	+	+	+	+
8	+	+	+	+	-

Note: Plus indicates when the factor is at its upper level, and minus indicates when the factor is at its lower level.

Penetration

The penetration of the recovered asphalt at 77 F was determined at 3-month time periods. Figure 2 shows the results achieved to 12 months. The following results are noted:

1. The penetration of the storage tank asphalt averaged 94. After mixing and

TABLE 3

SUMMARY OF TESTS CONDUCTED

Test	Type	Method	Response Measured	Temperature (deg F)	Remarks
Physical properties	Kinematic viscosity	AASHO T 202-63	Poises	140	Asphalt recovered from pavement cores by Utah State Highway Department Specification 8-946 and 8-951
	Penetration	AASHO T 49-64	Units penetration of standard needle under 100 gr load, 5 sec	77	
	Ductility	AASHO T 51-44	Elongation of specimen at rupture: rate 1 cm/min; response cm	39.2	
Strength properties	Stability	ASTM D 1559	Maximum load, lb	140	Samples are 4-in. diameter cores from pavements, not coated, soaked in water for 35 min
	Density	ASTM D 2726	gm/cm^3	77	
	Air void	Maximum density; (bulk density/maximum density)	Percent	77	
	Constant strain rate (uniaxial compression)	Measure stress-strain response to failure	Ultimate compressive strength, psi; ultimate compressive strain stiffness, psi	110, 70, and 20	See Refs. 2 and 4
	Diametral	Apply constant deformation rate diametrically until failure	Maximum load F, lb	70	Ultimate indirect tensile strength = $(2F/\pi dh)$, Refs. 2 and 4
	Stress relaxation	Apply constant strain ϵ_0 and measure stress	Axial stress as function of time $\sigma(t)$, psi	70	Relaxation modulus $D(t) = [\epsilon(t)]/\sigma_0$
Pavement properties	Dynaflect deflection	12 replications in wheelpath in each section	Maximum deflection (sensor 1), in. $\times 10^{-3}$	80 and 105^a	
	Rutting	8 replications in inner and outer wheelpaths in each section	In.	80 and 105^a	4-in. rut depth gage
	Skid resistance	At 40 mph in outer wheelpath	Coefficient of resistance	80 and 105^a	Mu-meter

[a] Pavement temperature.

laying, the average penetration of the asphalt dropped to 82. Average penetration at 12 months averaged 60. From the 3- to 6-month period, the pavement was below 50 F, thereby reducing the drop in penetration.

2. Rubber solids reduced the penetration about 24 points in the asphalt initially recovered from the pavements. This effect is somewhat reduced after 12 months in the pavements. The +S asphalt averaged 55 points, and the -S averaged 65.

3. The low-viscosity asphalt initially showed 14 points greater penetration, but after 12 months it showed only 3 points greater.

4. The percentage of asphalt in the mixture initially and up to 3 months had no effect on penetration of the recovered asphalt. However, at 6 and 12 months the lean mixtures showed significantly less penetration than the rich mixtures. This difference was caused by the greater air voids in the lean mixtures, allowing greater oxidation and volatilization of the asphalt.

Ductility

The ductility of the recovered asphalt at 39.2 F was determined from the core samples. Figure 3 shows the results achieved to 12 months after construction. The following results may be noted:

1. There seems to be considerable fluctuation of the ductility results with time. The average at 6 months was considerably higher than that initially, at 3 months, or at 12 months.

2. Synthetic rubber produced a marked effect on ductility at each of the time periods. The rubber initially produced a 27-cm increase in ductility, and after 12 months still produced a 22-cm increase. The nonrubberized asphalt pavements showed a very low ductility of 10 cm. The -S plot is accordingly the lowest shown in Figure 3.

3. Before mixing and compaction, the high-viscosity asphalt had a ductility 70 cm greater than that of the low-viscosity asphalt. However, after mixing and laydown, there was no significant difference in the +V and -V ductilities. With time the +V asphalt averaged somewhat greater ductility than the low-viscosity asphalt, but the difference is not statistically significant.

4. The percentage of asphalt did not show any significant effect on ductility of recovered asphalt properties up to 12 months.

MIXTURE PROPERTIES

Stability

The stability of cores cut from the outer wheelpath of the pavement was determined. The samples were soaked in a water bath at 140 F for 35 min before testing. Stability is defined in the Marshall test as the maximum compressive load in lb. The results to 12 months are shown in Figure 4. The following points are noted:

1. The overall increase in the stability of initial cores cut after compaction averaged 435 and 1,115 lb at 12 months. This reflects the general hardening or stiffening of the asphalt pavement properties.

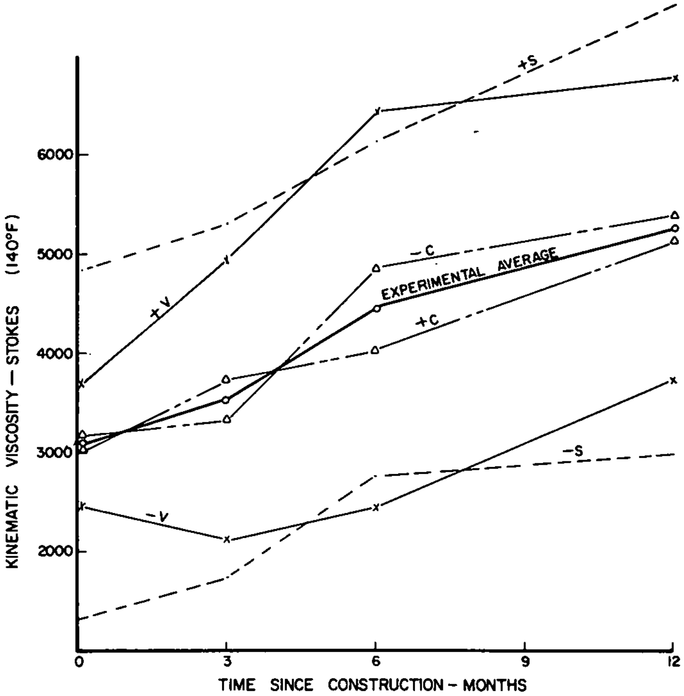

Figure 1. Changes with time of the levels of S, V, and C for kinematic viscosity of recovered asphalt at 140 F.

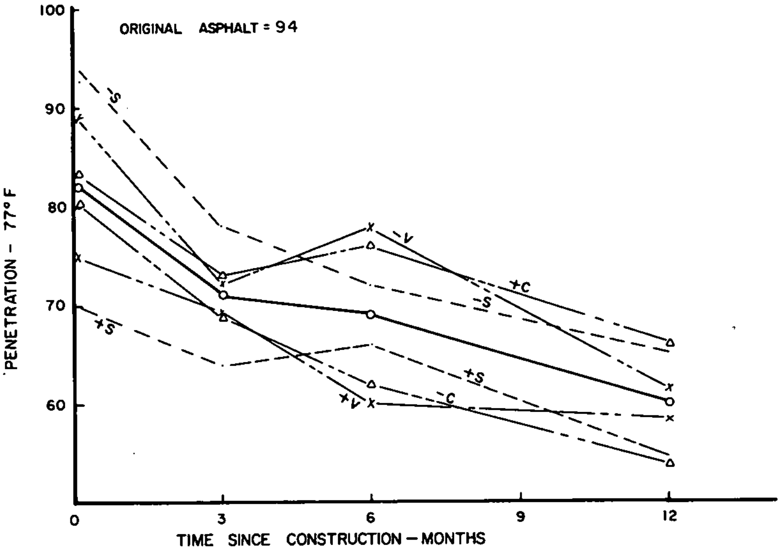

Figure 2. Changes with time of the levels of S, V, and C for penetration of recovered asphalt at 77 F.

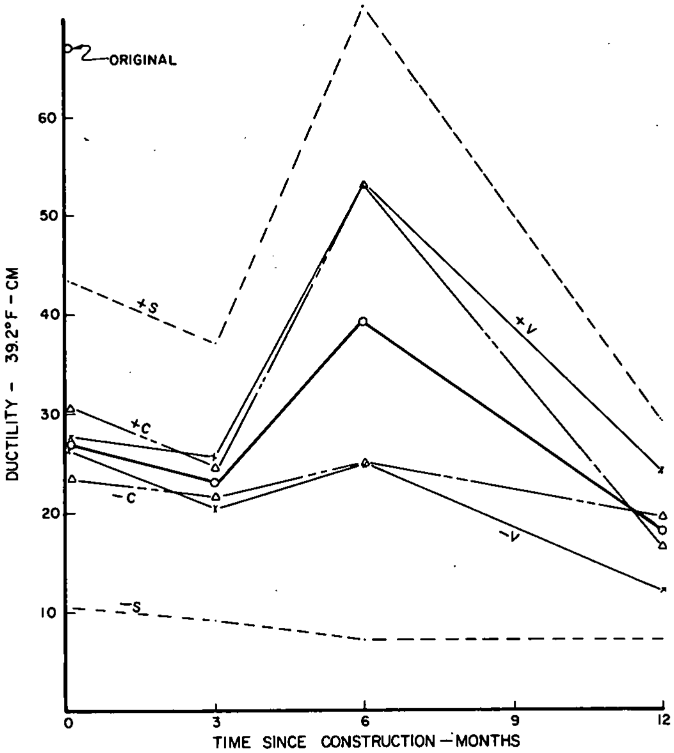

Figure 3. Changes with time of the levels of S, V, and C for ductility of recovered asphalt at 39.2 F.

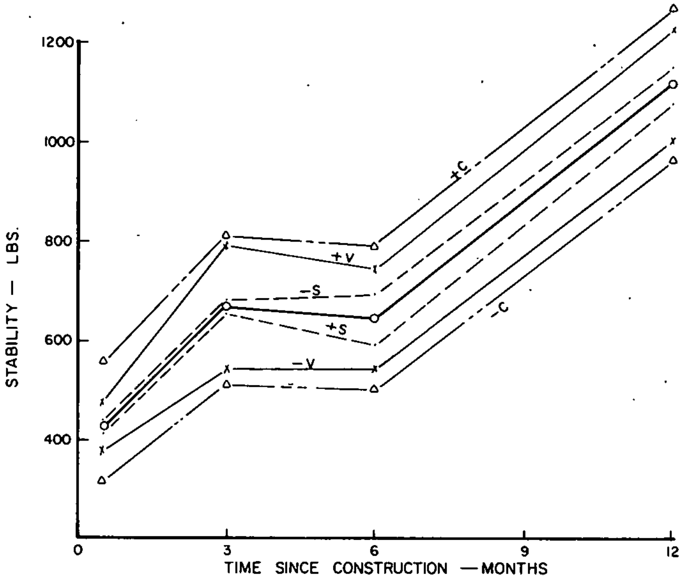

Figure 4. Changes with time of the levels of S, V, and C for stability of core samples at 140 F.

2. The rubberized pavement cores showed no significant increase in stability over the nonrubberized cores throughout the 12-month period.

3. The high-viscosity pavement cores showed significantly greater stability than the low-viscosity cores for every testing period to 12 months.

4. The rich-mixture pavement cores consistently showed much greater stability than the lean-mixture pavement cores, initially and up to 12 months after construction.

Density

The bulk density of the cores cut from the outer wheelpath of the pavement was determined. Figure 5 shows the results to 12 months.

1. The initial density was 132 pcf; the 12-month density was 142 pcf. There was a considerable increase in pavement density in the first 3 months, and no increase from the 3-month to the 6-month period. During the winter period, the pavement temperature averaged less than 50 F.

2. Synthetic rubber pavements produced 1.8 pcf less density initially and 2.0 pcf less density at 12 months than the nonrubberized pavements. Rubber did not retard the rate of densification of the pavements to 12 months.

3. Pavements with different viscosities showed no significant difference in density at each time period.

4. Asphalt content had a large effect on pavement density. The rich asphalt pavements (6.4 percent asphalt) averaged 4.7 pcf greater density than the lean asphalt pavements (5.2 percent asphalt).

Air Void

Air void content was determined from cores cut from the pavements at 3-month intervals. The results up to 12 months are shown in Figure 6. The following results are noted:

1. There was a general decrease in pavement air voids with time. This corresponds to the increase in density already noted.

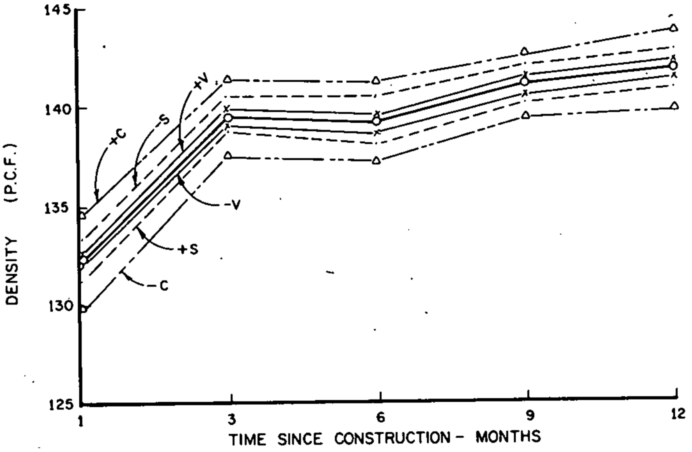

Figure 5. Changes with time of the levels of S, V, and C for density of core samples at 77 F.

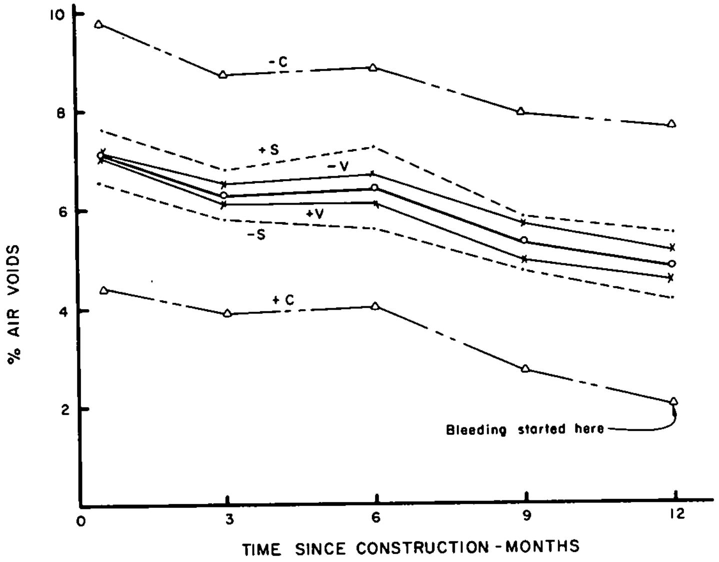

Figure 6. Changes with time of the levels of S, V, and C for percentage of air voids of core samples at 77 F.

2. The rubberized pavements showed slightly greater (1.2 percent) air voids than the nonrubberized pavements through the 12-month period. This result was also noted in the Marshall design properties. The rubberized mixtures required ½ percent greater optimum asphalt content.

3. The low- and high-viscosity asphalt pavements did not show any significant difference in percentage of air voids.

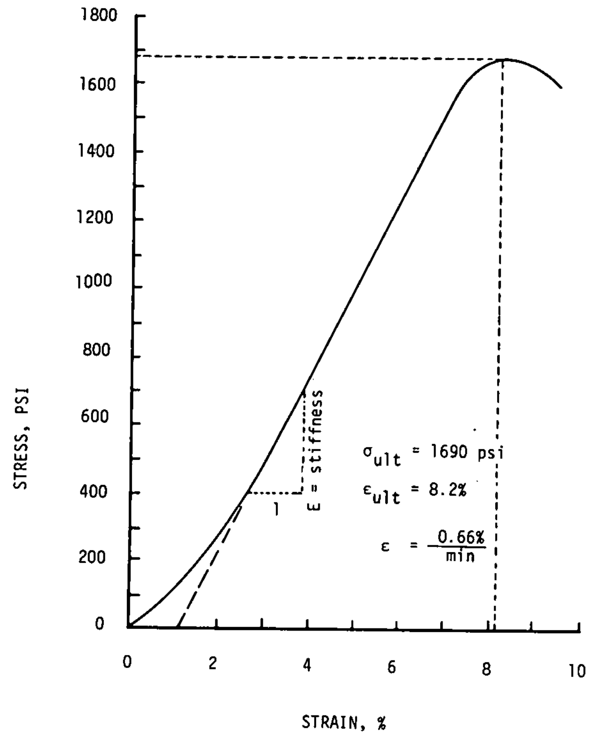

Figure 7. Typical curve of stress-strain at constant-strain rate.

4. Asphalt content had a very significant effect on the pavement air voids as it had on density. The rich pavements initially showed 4.4 percent voids and the lean 9.8 percent. As density increased with time, the average voids of the rich mixture became smaller and reached a level of 2 percent at the 12-month period. It was observed that during hot summer days the expanding asphalt filled all available void space and was forced to the top of the pavement in an irreversible process causing "bleeding."

Ultimate Compressive Strength, Ultimate Compressive Strain, and Stiffness

Cores 2 in. in diameter and 3 in. high cut from the inner wheelpath of the pavement and capped with a sulfur compound were tested under isothermal conditions at 3 temperatures, 20, 70, and 110 F. All the tests were performed at 0.02 in./min constant rate utilizing an Instron testing machine. Some additional tests at -20 F and at different rates were performed on the initial samples 2 weeks after construction (2, 4). All samples were tested beyond the maximum compressive strength. The failure mode of the test samples was, in general, shear failure at 110 and 70 F. At 20 F both shear failure and tensile failure were observed. Figure 7 shows some representative constant strain-rate-to-failure data. There is initially a "toe" or reversed curvature in almost all data, which is due to either small strain nonlinearity or internal rearrangement of aggregates.

Because of the viscoelastic nature of the material, the shape of each curve (and, therefore, ultimate strength, ultimate strain, and modulus) depends on strain rates. This strain-rate effect is not now being considered. Only the results from a constant deformation rate, which is approximately equal to constant strain rate, are considered. The test results of ultimate compressive strength, ultimate compressive strain, and stiffness of samples initially and at 6, 9, and 12 months are shown in Figures 8, 9, and 10. The following points are noted from the results of unconfined compressive strength as shown in Figure 8.

1. There was an overall increase in the average compressive strength of the samples from the initial to the 12-month period for all 3 temperature levels. At 20 F, the increase was from 1,260 to 1,580 psi; at 70 F, the increase was from 200 to 315 psi; and at 110 F, the increase was from 33 to 87 psi.

2. Only asphalt content showed a significant effect on the compressive strength at 20 F where the rich mixtures showed consistently greater strength than the lean mixtures throughout the 12-month period. At the high temperature, 110 and 70 F, the overall effect was not very consistent; although at the 12-month period, the rich mixtures showed less strength than the lean mixtures.

For the ultimate strain, the following results are noted:

1. At 110 and 70 F, the average strains were nearly the same from the initial to the 12-month period. However, there was an overall decrease in the average strains from 5.5 percent initially to 4.5 percent at 12 months at 20 F.

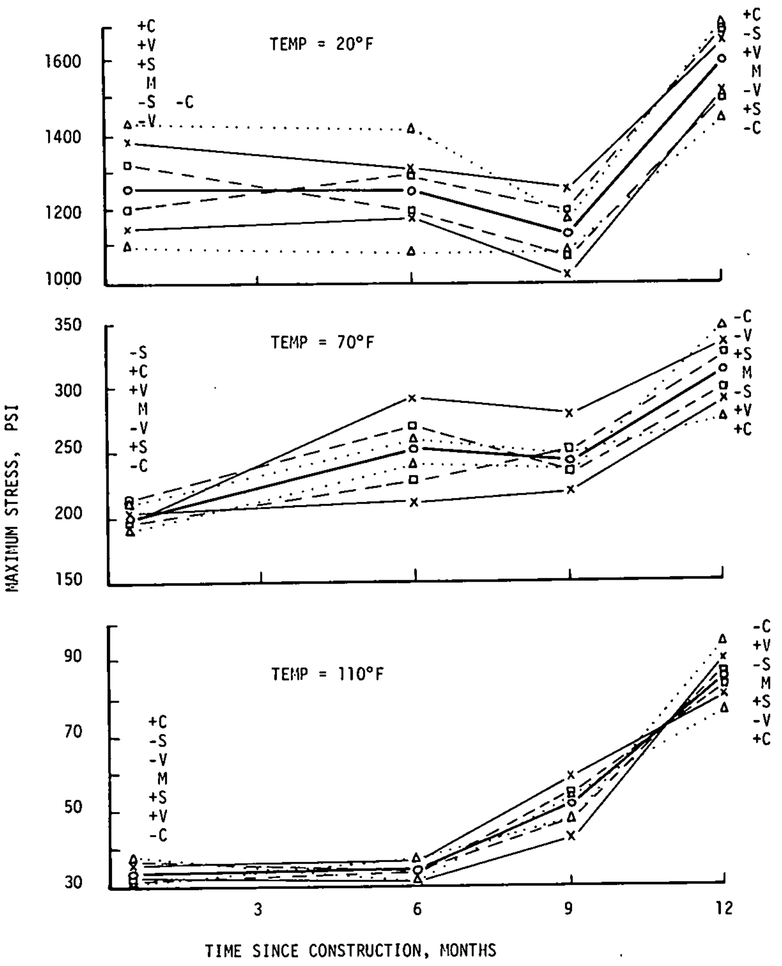

Figure 8. Change with time of the levels of S, V, and C for ultimate compressive strength at 20, 70, and 110 F.

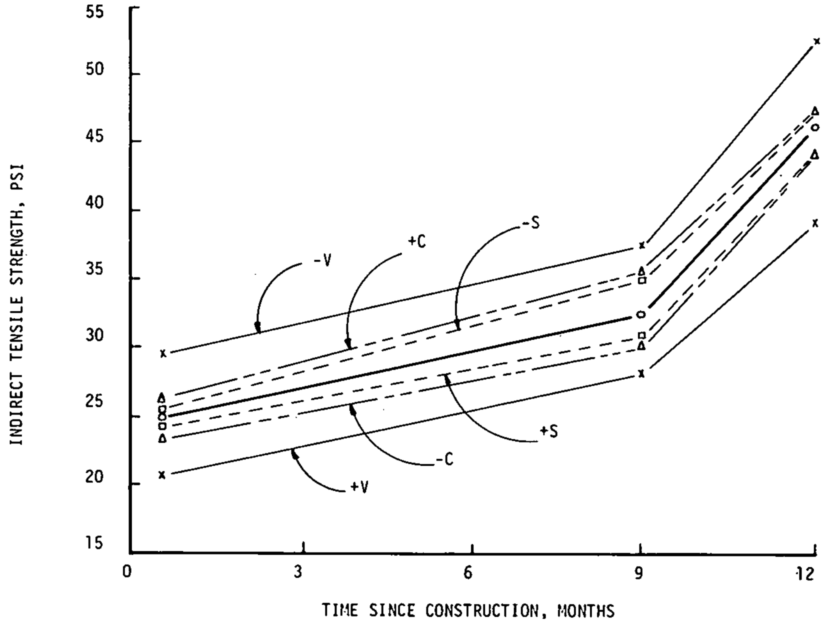

Figure 9. Changes with time of the levels of S, V, and C for indirect tensile strength at 70 F.

2. The rubberized mixtures showed significance only at the initial period where rubberized mixtures resulted in larger ultimate strain over the nonrubberized mixtures at 20 F; at 110 F, the effect was just the opposite.

3. At 20 F, the rich mixtures showed consistently larger ultimate strain than the lean mixtures throughout the 12 months. At 70 F, the rich mixtures, which originally have larger ultimate strain at the initial period, showed less ultimate strain at the 12-month period.

The results of stiffness indicate that there was an overall increase in the average stiffness of the samples from the initial to the 12-month period for all 3 temperature levels. At 20 F, the increase was from 37,200 to 46,500 psi; at 70 F, the increase was from 10,400 to 14,400 psi; and at 110 F, the increase was from 2,700 to 6,000 psi. The overall effect of S, V, and C on E throughout the 12 months is not very conclusive at this point; however, at 12 months the rich mixtures showed greater value of E for 20 F than the lean mixtures, and the opposite effect was observed for 70 and 110 F.

Indirect Tensile Strength

The core specimens 4 in. in diameter by 1 in. in height were tested at 70 F constant temperature at 0.02 in./min constant deformation rate diametrically until the samples failed. During the test, the failure was usually initiated at the center with a vertical crack and was gradually propagated in the vertical direction (along the direction of loading). The maximum tensile strength (σ_{ult}) is calculated by the following formula:

$$\sigma_{ult} = \frac{2\,Fmax}{\pi\,dh} \text{ (tension)}$$

where Fmax is the maximum load, and d and h are the diameter and the height of the specimen. The test results of initial, 9-month, and 12-month periods are shown in Figure 9. The following points are noted:

1. There was an overall increase in the average tensile strength from 25 psi initially to 46 psi at 12 months.
2. The rubberized pavement specimens showed no significant increase in strength over the nonrubberized specimens throughout the 12-month period.
3. Specimens with low-viscosity asphalt showed considerably greater tensile strength than the specimens with high-viscosity asphalt throughout the 12-month period. It has been pointed out in previous reports (2, 4) that the kinematic viscosity of the asphalt used was measured at 140 F. However, the cannon cone plate viscosity measurement conducted at 77 F indicated that the asphalt with low kinematic viscosity measured at 140 F actually had greater viscosity at 77 F. Therefore, the effect of the viscosity on the strength should be the opposite; namely, specimens with high viscosity (measured at room temperature) have greater tensile strength.
4. The rich mixtures showed consistently greater strength than the lean mixtures throughout the 12-month period.

Stress Relaxation Modulus

The specimens used in the stress relaxation tests are identical to those described earlier. The tests were conducted by utilizing an Instron testing machine that compressed the specimen at a very rapid crosshead speed to a predetermined displacement and then stopped the crosshead. The force versus the time was recorded automatically. The stress relaxation modulus at each given time was obtained by dividing the stress by the constant strain. In this paper, only the relaxation moduli at the short time (3 sec) and the long time (720 sec) and at 70 F testing temperature are presented. These are shown in Figure 10. The following results are noted.

1. There was no overall change of the short time ($t = 3$ sec) relaxation modulus from the initial to the 12-month period; however, the longer time relaxation modulus decreased from 2,800 psi initially to 1,900 psi at 12 months.
2. Specimens with low-viscosity asphalt (measured at 140 F) showed considerably greater short-time and long-time relaxation moduli than the specimens with high-viscosity asphalt at the initial period and at the 12-month period. However, as discussed earlier, the actual viscosity of the asphalts used near room temperature was opposite to the viscosity measured at 140 F. Therefore, specimens with high-viscosity asphalt will actually result in a larger relaxation modulus.
3. The rubberized specimens showed significantly greater short-time and long-time relaxation moduli initially and at 12 months than the nonrubberized specimens. An analysis of variance of S, V, and C effects indicated that SC interaction is very significant (1 percent) for short-time relaxation modulus at 12 months and for long-time relaxation modulus initially and at 12 months. Rubberized specimens showed significantly larger relaxation modulus than the nonrubberized specimens among the rich mixtures. For the lean mixtures, rubber additives had no significant effect on the relaxation modulus as shown in Figure 11. The results of long-time relaxation modulus at 12 months also showed significant SV interaction for rubberized specimens that had significant larger relaxation modulus than the nonrubberized specimens among the low-viscosity asphalt mixtures (Fig. 11).

PAVEMENT PROPERTIES

Deflections

Deflections of the pavement structure were determined with a Dynaflect at 3-month intervals after construction. The results are shown in Figure 12. The average deflections of the thick (+T) and thin (-T) surfaces, thick (+B) and thin (-B) base courses, high (+V) and low (-V) asphalt viscosities, and rich (+C) and lean (-C) asphalt contents have been plotted. There are 8 test sections at each of these levels for each factor, so that each point is an average deflection of 8 independent sections. The following results are noted:

1. The largest effect was the thickness of surface course. The +T = 5.7-in. pavement showed about 25 percent less deflection than the -T = 3-in. pavement. Analysis

of variance showed T significant at the 0.1 percent significance level. Magnitude of this effect varied considerably with pavement temperature. The largest effect of T was at the 3- and 6-month-periods when the pavement temperature was 56 and 48 F respectively. At the initial, 9-month, and 12-month periods, the pavement temperature was 84, 115, and 105 F respectively. The Dynaflect deflections were correlated with creep speed deflections of the Benkelman beam at the 12-month period. On the experimental project the approximate Benkelman beam deflection may be determined as follows: Benkelman beam deflection (in.) = 25 × Dynaflect maximum deflection × 10^{-3}.

2. The thickness of base course was the next largest effect and had some significance (5 percent) at several of the time periods. The 4-in. bas showed about 10 percent less deflection than the 2.2-in. base at most time periods.

3. The factors V, C, or S were not significant in effecting the deflection of the pavement. This is a surprising result because S, V, and C have had significant effects on the strengths of the materials. This result showed the great effect that thickness of surface course has on deflections as opposed to the material properties of the surface.

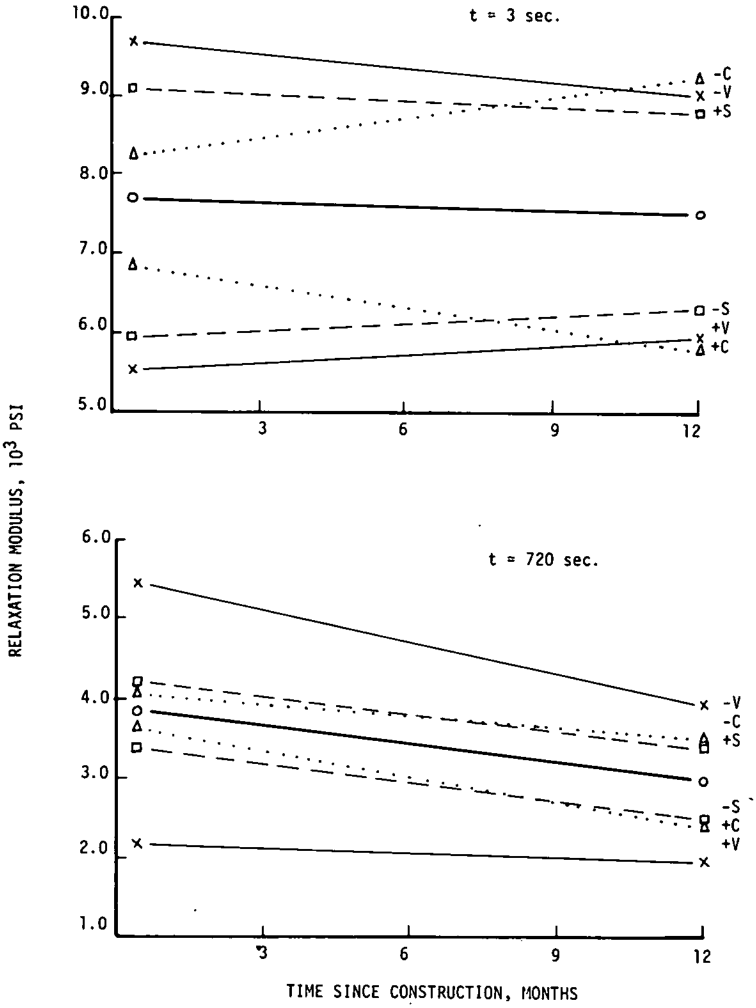

Figure 10. Changes with time of the levels of S, V, and C for relaxation modulus at 70 F.

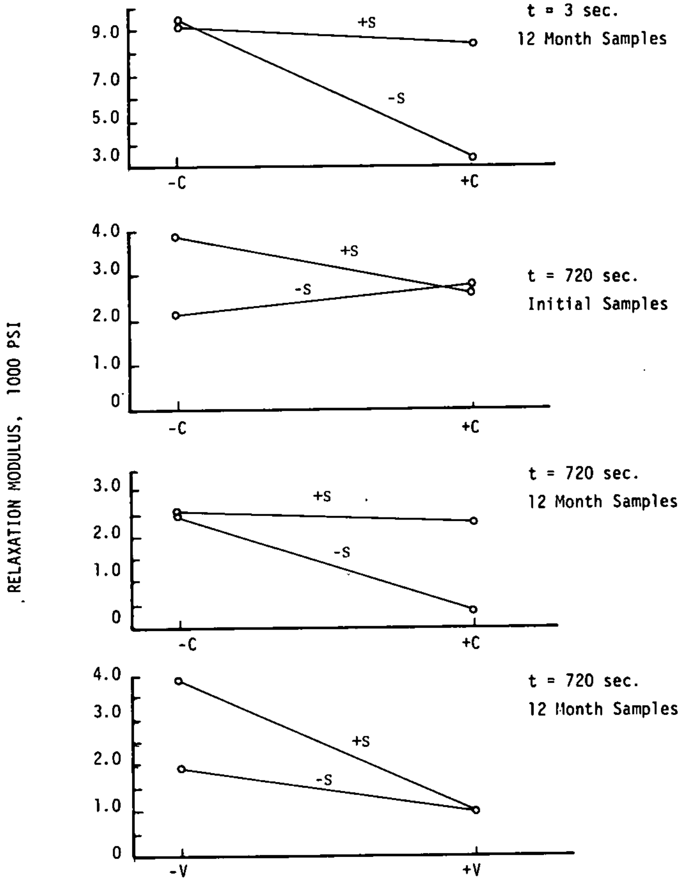

Figure 11. Interaction of S with C and V on relaxation modulus.

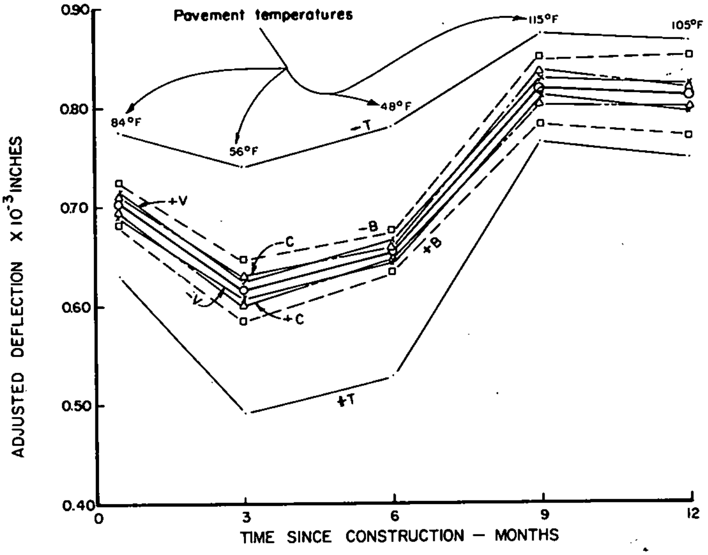

Figure 12. Changes with time of the levels of T, B, V, and C for deflections of pavement surface.

Rut Depth

TABLE 4

ANALYSIS OF VARIANCE FOR RUTTING AT 12-MONTH PERIOD

Source of Variation	Degrees of Freedom	Mean Effect (in.)	Mean Square $\times 10^{-3}$	Significance (percent)
Main Effects				
T	1	0.029	28	5
B	1	0.011	4	
S	1	-0.022	15	
V	1	-0.009	2	
C	1	0.037	44	1
Interactions				
TB	1	-0.002	0	
TS	1	-0.013	5	
BS	1	-0.005	1	
CV	1	0.011	4	
TV	1	-0.015	7	
BV	1	-0.007	2	
CS	1	-0.011	4	
SV	1	0.038	47	1
BC	1	-0.001	0	
TC	1	0.024	18	
iwp-dwp	1		134	
Lanes	1		1	
Replication	1		0	
Error	103		5	
Total	127			

Additional factors: $n = 128$, $\bar{X} = 0.098$ in.

Rut depth measurements were taken on the test sections at the 12-month period. They were taken by means of a 4-ft rut depth gage on the inner and outer wheelpaths. An analysis of variance was run on the data, and the results are given in Table 4. The most significant factor was asphalt content, which showed the rich mixtures were rutting greater than the lean mixtures. The interaction SV was also significant at the 1 percent level where the pavements containing low-viscosity asphalt without rubber showed the greatest rutting. When 3 percent rubber solids were added to this asphalt, the rutting was significantly reduced. Rubber content seems to have no real effect on the magnitude of rutting of the high-viscosity asphalt pavements. Also the low-viscosity asphalts rutted significantly more than the high-viscosity pavements when each did not contain rubber solids. Both high- and low-viscosity asphalts had about the same penetration even though they had greatly different viscosities. The rutting was not very great at the 12-month interval; but if these trends continue, more significant results will be obtained in the future. The factor T showed only moderate significance at the 5 percent level. The thicker pavements were rutting more than the thinner pavements. This rutting was due primarily to densification of the surface as has been discussed.

DISCUSSION OF FINDINGS

The 3 asphalt properties—kinematic viscosity, penetration, and low temperature ductility—all showed a general hardening or stiffening throughout the 12-month period. Kinematic viscosity (140 F) increased, penetration (77 F) decreased, and ductility (39.2 F) was somewhat variable with an increase during the winter but with a small overall average drop from the initial to the 12-month period.

The 3 pavement mixture properties of density, voids, and stability showed considerable changes during the 12 months. The density of the pavements increased rapidly in the first 3 months of service and then leveled off during the winter period as the voids decreased and the stability of the pavement cores increased. After the winter period the density increased, and the air voids decreased at a slower rate. The stability increased very rapidly, however, from the end of winter (6 months) to the 12-month summer period. These changes in density, voids, and stability are in accord with the theoretical concepts of the Marshall design. The initial 3-month increase of stability was due mostly to the rapid rate of traffic densification. However, it is felt that the stability increase was also due to a hardening effect of the asphalt cement binder. The reduction of air voids of the pavements to 2 percent in the rich pavements has already shown itself as bleeding, as observed during the 9- to 12-month period.

Among the 5 mechanical properties of the mixtures studied, ultimate compressive strength, stiffness, and indirect tensile strength showed an overall increase from the initial period to the 12-month period. The change of these properties was due mostly to the traffic densification and to a hardening of the asphalt. The relaxation modulus at the short time was nearly constant, while the longer time relaxation modulus decreased from the initial period to the 12-month period. However, an increase in the short-time relaxation modulus should be expected in accord with the increase of the stiffness from the initial period to the 12-month period. This inconsistency could be due to the small strain nonlinearity as shown in Figure 7. Ultimate compressive strain showed a slight decrease from the initial period to the 12-month period. This could also be caused by the hardening of the asphalt in the mixtures.

Pavement characteristics of rutting and deflections are especially interesting. The rutting of the pavements showed definite significance of asphalt content, C, and a rubber-viscosity, SV, interaction. The rich pavements showed significantly greater rutting than the lean pavements at the 12-month period. This result can be directly related to the relaxation tests (Fig. 10) and the maximum strength (Fig. 8) and stiffness properties of the rich and lean pavements. At temperatures of 70 and 110 F the rich pavements showed significantly less strength and stiffness than the lean pavements. The low-viscosity asphalt pavements showed considerably greater rutting than the high-viscosity pavements. This result can be associated with the stability test at 140 F that showed throughout the 12-month period that the high-viscosity asphalt pavement had significantly greater stability than the low viscosity. The low-viscosity pavements that contain rubber solids showed significantly less rutting than those without rubber solids. The stress relaxation test showed that at the 12-month period (at larger periods of loading somewhat like a repeatedly loaded pavement) rubber in the low-viscosity asphalt pavements resulted in a large relaxation modulus as compared to low-viscosity pavements without rubber. The presence of rubber solids in the low-viscosity pavements seemed to have an effect of strengthening the binder more effectively and consequently increased the relaxation modulus and decreased rutting.

The thickness of surface course was found to have by far the largest effect on deflections than any one of the other 5 factors. The thicker surfaces (5.7 in.) showed much less deflection than the thinner surfaces (3 in.). Asphalt content, rubber solids, or viscosity of asphalt had little or no effect on deflections throughout the 12-month period. However, the effect of T was dependent on the temperature as shown in Figure 12. The overall deflection was highly dependent on the pavement temperature. This result is reflected by the strength tests at 20, 70, and 110 F (Fig. 8).

SUMMARY

In the first 12 months of this designed experiment, many significant facts have been disclosed. They are all based on data statistically analyzed and highly significant at the 1 to 0.1 percent probability level. Among these findings are the following:

1. There has been a hardening, generally, of the asphalt binder in the paving mixtures as measured by viscosity, penetration, and ductility. The amount of hardening was influenced by the amount of asphalt in the mixture. The pavements with high air voids (9.8 percent) showed significantly greater asphalt hardening than the pavements with low air voids.
2. Densification was due primarily to the action of the traffic load. It is evident in the development of slight depression in the traffic lanes, rutting, and other similar displacement phenomena. Attendant reduction in voids and change in stability are as suggested in the Marshall design theory. Densification to the point of causing the voids to be overfilled with asphalt and causing bleeding has been observed.
3. The phenomenon of rutting was found to be related not only to the mixture components and composition that change the internal structure of the pavement mixture but also to the thermo-viscoelastic measurement, such as relaxation tests and direct compression tests. Rutting was also significantly related to the Marshall stability test. Rubber definitely reduces rutting in the low-viscosity asphalt pavements.
4. Skid resistance was significantly (1 percent) affected by rubber solids. Pavements with 3 percent rubber solids showed greater skid resistance than pavements without rubber.
5. Thickness of surface course and base course were highly significant in affecting the pavement deflections. Pavement temperature was found to have a large effect on these measured deflections.

The selection of information noted in this paper confirms that statistically designed field and laboratory experiments are producing significant information about many of the properties of actual highway pavements during the first 12 months in service. The 16 pavements contain widely varied characteristics and design properties. The experiment is evidently sensitive enough to measure changes in the compositions and structure of the experimental sections from initial service to 12 months at high significance levels.

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REFERENCES

1. Darter, M. I., and Vokac, R. Use of Synthetic Rubber-in-Asphalt Pavement to Determine Mixture Behavior and Pavement Performance. Utah State Highway Department, interim rept., 1969.
2. Fitzgerald, J. E., and Lai, J. S. The Effect of Rubber Additives on the Thermorheological Properties of Asphalt Mixtures. Civil Eng. Dept., Univ. of Utah, July 1969.
3. Darter, M. I., Peterson, D. E., Jones, G. M., and Vokac, R. Design, Construction, and Initial Evaluation of Experimental Test Sections of Asphalt Containing Synthetic Rubber. Highway Research Record 313, 1970, pp. 1-17.
4. Fitzgerald, J. E., and Lai, J. S. Initial Evaluation of the Effect of Synthetic Rubber Additives on the Thermorheological Properties of Asphalt Mixtures. Highway Research Record 313, 1970, pp. 18-31.