Dynamic Tests on the Stability of Bituminous Mixtures for Pavement at Low Temperature (II)

Experimental Researches on Rubber Blended Asphalt and Asphalt Mixtures

By

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Synopsis

Investigations on the effects of the inclusion of rubber with the bituminous materials used in paving mixtures were made at low temperatures down to −50°C.

These tests were concerned with the changes of physical properties that occur when natural rubber powder was blended with petroleum asphalts.

This report shows that natural rubber powder in the amount of 3 to 10% affects the physical properties of asphalts. The changes in the physical properties of a given asphalt become more pronounced with increases in the rubber contents in the asphalt or in the asphalt mixtures.

In general, the impact resistance was increased by the addition of rubber, while the penetration was affected by the heating time and the method of blending. In some cases, although the penetration decreased, values of other factors under test increased. Softening point and viscosity increased, ductility decreased.

It was only in the test of elastic properties of asphalt mortar measured by a sonic device, that marked differences were found.

The test pavement was constructed by the authors as a part of the Wattsu section between Sapporo city and Chitose Air Port. This test road was subjected to heavy service of winter traffic. After one winter of service, it was clear that the rubber blended asphalt pavement has high resistance to abrasion. Furthermore the utility of rubber blended asphalt pavement was confirmed.

The ultimate object of these studies is to improve the bituminous pavement in cold districts.

Chap. 1 General description

In cold weather the bituminous pavements are usually damaged. The causes of damage are the low temperature, the special traffic conditions, the change of the physical properties, and the freezing and thawing actions occurring in the presence of water.

In recent years much attention has been given to improvement of the asphalt mixtures.

Prior to the present investigation, tests concerning impact resistance, temperature sensitivity and elastic properties of the conventional asphalt mixtures had been made by the present authors[1]. As to the results of these tests, it may be said, in general, that the characteristics of the bituminous mixtures depend upon the character of the asphalt used in the mixtures; there were some differences of values of the impact resistances in the mixtures made with various amount and kinds of asphalts, but there was on remarkable variation in temperature sensitivity and the slope of log. toughness-temperature relation. If it is desired to alter these last two characteristics, the asphalt itself should be improved.

Attention has been directed, in recent years, to the experimental uses of rubber blended asphalt pavement.[2),3),4),5),6),7),8),9),10)]

Claims have been made that the use of rubber extends the life of the bitumens, gives them more elastic properties at high temperature, increases the resistance to shock at low temperature, decreases their slipperiness, promotes resistance to water action, and reduce maintenace costs.

Several weak points in conventional flexible pavement need very much to be improved.

In view of these considerations, some investigations concerning shock resistance and temperature sensitivity were performed by the present authors.

Several methods and several kinds of apparatus were used to study the physical properties of rubber blended mixtures.

In these tests special attention was paid to the impact resistance, and the visco-elastic properties of the mixture at temperatures lower than 0°C. In the present investigation, the range of low temperature was widened to as low a point as −50°C.

The impact resistance was obtained by using a Page impact testing machine; visco-elastic properties were measured by a sonic apparatus.

The amount of rubber added were 3, 5, 7 and 10% of the asphalt because this range represents the quantity generally employed in actual road construction at present. The rubber used was a natural rubber powder "Mealorub". The asphalt used was a kind of straight asphalt produced from Akita, Japan.

Chap. 2 Properties of rubber-blended asphalt

1. Preparation of specimens.

The properties of asphalt used are as follows:

specific gravity	25°C/25°C	: 0.999
penetration	25°C 100 gr., 5 sec.	: 80
do.	0°C 200 gr., 60 sec.	: 40
softening point		: 45°C
float test	at 80°C	: 60 sec.
ductility	at 25°C	: 86 cm.
flash point		: 193°C
burning point		; 273°C

In one mixture, the rubber powder was pre-blended by heating the asphalt to 130°C., adding the required amount of rubber, and stirring the rubber-asphalt blend for about 2 hours at 130°C. (sample A). In another mixture, the powdered rubber was added to the hot asphalt, and after 20 hours of stirring at 130°C, the rubber-asphalt blend was poured into the separate moulds (sample B).

2. Effect on penetration.

The apparatus used was a standard type penetrometer specified in A. S. T. M. D-5, 25. The test temperature, load and applying time were 25°C, 100 gr., 5 sec.; 0°C, 100 gr., 5 sec.; and 0°C, 200 gr., 60 sec., respectively. Table 1 to Table 4 and Fig. 1 show the relation of penetration, rubber contents and test temperature. As to the results, it was found that the grade of the variation of penetration depends on length of heating period.

TABLE 1 Penetration of Sample A at 25°C, 100 gr., 5″

	0 %		3 %		5 %		7 %		10%	
1	77	72	54	47×	41	43	42	46	42	36
2	57×	77	51	55	43	59×	43	39	34	47×
3	68	68	50	53	48	58×	39	46	32×	50×
4	65	70	56	45×	47	51	38	44	33	39
5	71	68	56	52	50	53	39	45	32×	33
6	66	71	54	51	58×	52	44	38	37	42
Avre.	70.3		53.2		47.5		41.9		37.0	

TABLE 2 Penetration of Sample A at 0°C, 100 gr., 5″ and 0°C, 200 gr., 60″

	Sample A 0°C, 100 gr, 5″					Sample A 0°C, 200 gr, 60″				
	0 %	3 %	5 %	7 %	10%	0 %	3 %	5 %	7 %	10%
1	15	13	13	9	13	43	14×	30	31	25
2	12	13	8	17×	12	41	38	40	28	29
3	12	11	12	12	11	47	25×	40	30	28
4	13	9	13	12	10	48	37	37	27	26
5	10	16×	14	9	11	44	40	38	26×	26
6	10	17×	11	13	11	45	36	34	30	22×
Aver.	12.0	11.5	11.8	11.0	11.3	44.7	37.8	36.5	29.5	26.8

TABLE 3 Penetration of Sample B at 25°C, 100 gr., 5″

	0 %		3 %		5 %		7 %		10%	
1	82	83	58	61	82×	59	82	81	168	159
2	82	81	60	64	76	72	80	84	175	159
3	81	89	53×	67	81×	61	79	79	169	159
4	82	84	61	61	74	64	80	91	169	151
5	75	83	65	70	68	67	84	90	155	157
6	85	86	65	68	66	64	83	90	169	160
Aver.	82.7		63.6		67.1		83.6		162.5	

TABLE 4 Penetration of Sample B at 0°C, 200 gr., 60"

	0 %		3 %		5 %		7 %		10%	
1	32×	40	26	28	39×	32	35	38	68	65
2	40	44	34	34	29	33	34	38	74	70
3	44	44	28	28	27×	34	40	46×	63	70
4	34	44	37×	30	34	33	35	42	70	67
5	34	35	31	29	28	33	37	42	69	67
6	37	41	27	29	33	35	39	39	69	74
Aver.	39.7		29.5		32.4		38.1		68.8	

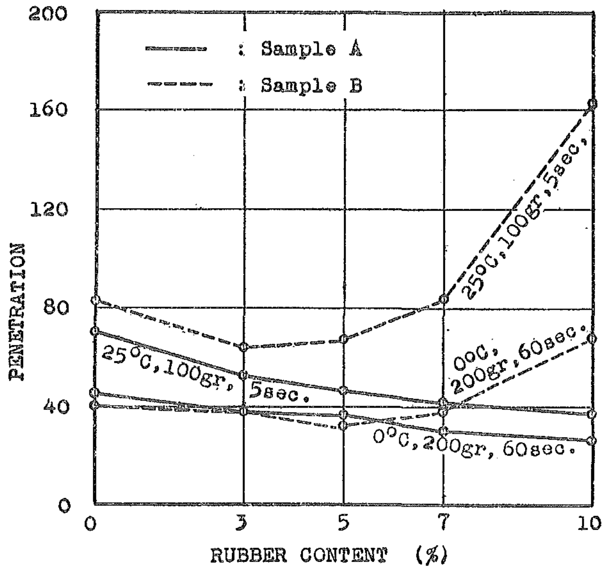


Fig. 1 Penetration of rubber blended ashpalt.

In the case of sample A, the penetration value was decreased proportionally to increase of rubber content, from 70.3 to 37.0 at 25°C, 100 gr., 5 sec.; from 12.0 to 11.3 at 0°C, 100 gr., 5 sec.; and 44.7 to 26.8 at 0°C, 200 gr., 60 sec.. In the case of sample B, the penetration was decreased by 3% addition, but the penetration was increased by addition of amounts larger than 5% rubber. The values were 82.7 in 0% rubber contents, 63.6 in 3% and 162.5 in 10% at 25°C, 100 gr., 5 sec., ; and 39.7 in 0%, 29.5 in 3% and 68.8 in 10% at 0°C, 200 gr., 60 sec.

That is to say, in sample A heated and stirred for a short period, the blend containing large amount of rubber powder had a small penetration, while the long-period-heated blend showed increases of penetration with increase of the rubber contents.

TABLE 5 Softening Point (°C)

Rubber content / No.	0 %	3 %	5 %	7 %	10%
1	44.8	52.0	55.4	59.8	61.2
2	45.2	52.0	56.2	60.0	61.4
3	45.5	52.4	56.2	60.0	61.4
4	45.5	52.5	56.6	60.0	61.5
Aver.	45.2	52.2	56.1	60.0	61.4

3. Effect on softening point.

The softening point was measured on sample B. This was done after about 20 hours of mixing, at the end of which period, the blend was removed from the heating kettle, moulded and tested. The results of the softening point tests on sample B of which the rubber content was 0 to 10% by weight of the asphalt, are given in Table 5 and Fig. 2.

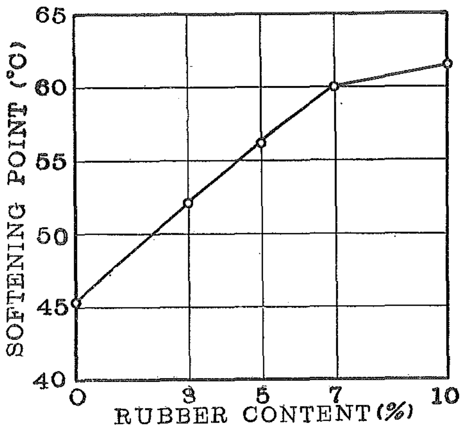


Fig. 2 Relation between softening point and rubber content of rubber blended asphalt.

To generalize, the softening point ran from 45.2 in 0% to 61.2 in 10%.

4. Float test.

The method of preparation of the specimens of the rubber asphalt blend are the same as those for penetration tests. The test temperature was 80°C. The result shows an increase of amount of rubber blending brings increase in the float value as indicated in Table 6 and Fig. 3.

5. Ductility test.

Ductility values of the asphalt samples at 25°C were greatly decreased by the addition of natural rubber powder. This tendency was

TABLE 6 Float test (at 80C°)

Rubber content / No.	0 %	3 %	5 %	7 %	10%
1	63	116	177	178	256
2	56	136	148	222	230
Aver.	60	126	163	200	243

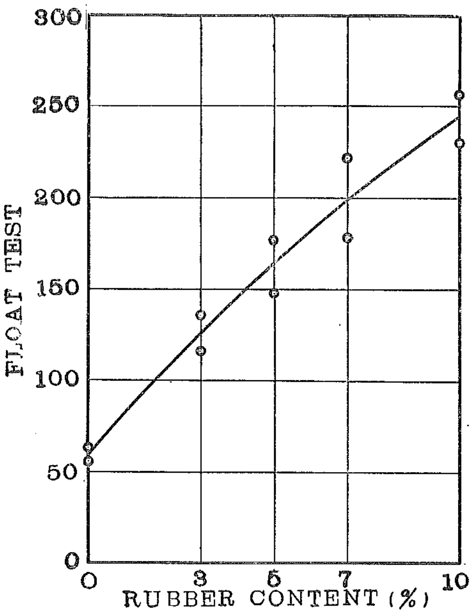


Fig. 3. Relation between float test value and rubber content of rubber blended asphalt.

remarkable in 3% addition, the ductility of 3% rubber blended asphalt being about 1/8 that of 0% rubber content. This result is shown in Table 7 and Fig. 4.

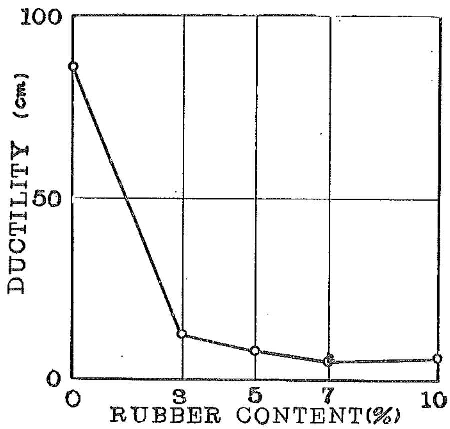


Fig. 4. Relation between ductility and rubber content of rubber blended asphalt.

TABLE 7 Ductility (at 25°C)

Rubber content / No.	0 %	3 %	5 %	7 %	10%
1	77	10	7	4	6
2	88	12	8	4	6
3	89	13	8	5	6
4	73	11	7	4	5
5	88	11	8	5	7
6	99	—	10	7	7
Aver.	86	11	8	5	6

6. Specific gravity, Flash point, and Burning point.

No remarkable differences were found in the tests of specific gravity, flash point and burning point. Results are tabulated in Table 8.

TABLE 8 Flash point, Burning point, and Specific gravity

Rubber content / Items	0 %	3 %	5 %	7 %	10%
Flash Point (°C)	193	216	208	205	210
Burning Point (°C)	237	257	230	239	248
Specific gravity 25°C/25°C	0.999	0.994	0.994	0.993	0.994

7. Temperature sensitivity of rubber blended asphalt[5].

Many investigators have shown that the addition of rubber reduces the susceptibility of the asphalt to changes in temperatures. A previous study by J. Ph. Pfeiffer has shown that the slope of log. penetration-temperature curve, is indicative of the temperature sensitivity of an asphalt.

Furthermore, others have shown that the float test index gives a true measurement of a temperature sensitivity. Then susceptibility factor, log. temperature curve, and float test index were calculated.

a. Susceptibility factor.

There are many methods for calculation of the tempepature sensitivity of an asphalt based on the ratios among 2 or 3 points of the penetration. In this test, the calculation of a susceptibility factor (S. F.) was based upon the relationship:

$$\text{S. F.} = \frac{\text{penetration } 25°\text{C, } 100 \text{ gr., } 5 \text{ sec.}}{\text{penetration } 0°\text{C, } 200 \text{ gr., } 60 \text{ sec.}}$$

b. Penetration index.

J. Ph. Pfeiffer and P. M. Van Doormal have described a method of calculating the asphalt by means of a "Penetration index". In calculating such an index, the penetration at a softening point was assumed as 800, then the equation of calculation is as follows:

$$\text{P. T. S.} = \frac{\log. 800 - \log. p}{t - 77}$$

where P. T. S. : penetration temperature susceptibility.

p : penetration at 25°C, 100 gr., 5 sec.
t : softening point, °F.

An asphalt rubber blend having comparatively low penetration index is comparatively more stable to change of temperature. This equation is the slope of the log. penetration temperature curve for the assumed penetration p at the temperatures t and 77°F respectively. The penetration value is then used in calculating the penetration index (P. I.) by the equation:

$$\text{P.I.} = \frac{30}{1+90\,(\text{P.T.S.})}$$

An asphalt having high temperature-penetration susceptibility has the charactor of low sensitivity to temperature changes.

c. Log. penetration-temperature slope.

It is not always certain that the penetration of some aspahlt is 800 at the softening point; then it is needful to get the true sensitivity by a penetration measurement[5]. It is necessary to determine the penetration at two different temperatures of t_1 and t_2 respectively.

The slope can be calculated as follows:

$$\text{slope} = \frac{\log.\, p_2 - \log.\, p_1}{t_2 - t_1}$$

where p_1 and p_2 are the penetration at the two temperatures t_1 and t_2 respectively.

d. Float test index.

The float test index is used to measure the susceptibility of an asphalt to change in temperature. The index can be calculated as follows:

$$\text{F.I.} = \sqrt{F. \times P.}$$

were F. I. : float test index.
F : float value at 80°C in seconds.
P : penetration at 25°C, 100 gr., 5 sec.

e. Conclusions.

The temperature sensitivity as calculated by the above 5 methods respectively are shown in tables.

Susceptibility factor (Table 9, Table 10):

TABLE 9 Susceptibility Factor and Log-penetration Temperature Slope of Rubber Blended Asphalt (Sample A)

Items \ Rubber content	0 %	3 %	5 %	7 %	10%
P_2 : 77°F (25°C), 100 gr., 5 sec.	69.2	53.1	51.1	41.9	36.3
P_1 : 32°F (0°C), 100 gr., 5 sec.	12.0	11.5	11.8	11.0	11.3
P : 32°F (0°C), 200 gr., 60 sec.	44.7	37.8	36.5	29.5	26.8
P_2/P: Susceptibility Factor	1.55	1.41	1.40	1.42	1.36
$\log P_2$	1.840	1.726	1.709	1.622	1.560
$\log P_1$	1.079	1.061	1.072	1.042	1.053
$\log P_2 - \log P_1$	0.761	0.665	0.637	0.580	0.507
slope: $(\log P_2 - \log P_1)/(T_2 - T_1)$	0.0169	0.0148	0.0142	0.0129	0.0113

TABLE 10 Susceptibility Factor of Rubber Blended Asphalt (Sample B)

Items \ Rubber content	0 %	3 %	5 %	7 %	10%
P_2 : 77°F (25°C), 100 gr., 5 sec.	82.7	62.7	69.5	82.9	162.3
P : 32°F (0°C), 200 gr., 60 sec.	39.1	30.1	32.5	38.8	68.5
P_2/P Susceptibility Factor	2.12	2.08	2.14	2.13	2.38

The results of tests show that the susceptibility of sample A decreases proportionally to increase of rubber contents.

This value decreased from 1.55 at rubber content 0% to 1.35 at rubber content 10%. This tendency indicates that the addition of rubber brings about the lowering of the temperature sensitivity. For sample B (long-period heating), the susceptibility factor was decreased by 3% rubber addition, and then upon the addition of amounts larger than 3%, the susceptibility was increased from 2.1 to 2.4. This result shows that the long-period-heated blend has high temperature sensitivity as proven by this method of measuring the penetration at two temperatures. Generally, sample B showed larger sensitivity than sample A.

Penetration temperature susceptibility (P. T. S.) (Table 11):

In the case of sample A, P. T. S. of 0 to 5% rubber blended was decreased proportionally to rubber content; between 5% and 7% the P. T. S. line was nearly a flat curve, and 10% rubber blend showed

TABLE 11 Penetration Temperature Susceptibility (P. T. S.) of Rubber Blended Asphalt

	Items \ Rubber content	0 %	3 %	5 %	7 %	10%
	Softening Point t °F	113	126	133	140	143
	$t-77$	36	49	56	63	66
Sample A	Penetration (25C°, 100 gr., 5″)	69.2	53.1	51.1	41.9	36.3
	log P	1.840	1.726	1.709	1.622	1.560
	log 800 − log P	1.064	1.178	1.195	1.282	1.344
	P. T. S.	0.0296	0.0240	0.0213	0.0202	0.0204
Sample B	Penetration (25°C, 100 gr., 5″)	82.7	62.7	69.5	82.9	162.3
	log P	1.918	1.797	1.842	1.918	2.221
	log 800 − log P	0.986	1.107	1.062	0.986	0.684
	P. T. S.	0.0274	0.0226	0.0190	0.0157	0.0104

larger value than the blend of 7% rubber content. In sample B, P. T. S. was decreased proportionally to rubber content. This tendency shows that the long-period-heated blend has lower sensitivity than that of short-period-heated blend as estimated by P. T. S. method.

Penetration index:

Penetration index is calculated by P. T. S., then this result is the same as that obtained by P. T. S.

TABLE 12 Penetration Index

P. I. \ Rubber content	0 %	3 %	5 %	7 %	10%
Sample A	− 1.8	− 0.5	+ 0.3	+ 0.6	+ 0.5
Sample B	− 0.4	− 0.1	+ 1.1	+ 4.0	+ 5.5

Float test index:

As for sample A, the float test index was increased, between 0 to 7% rubber content from 70 to 90, and on 10% content sample the index reached to 93. Generally, low sensitive asphalt has 90 or more float test index, then if the index is less than 90, the rubber addition brings about increases to 90 or more, satisfactorily; then this blend of low % rubber content can be used to decrease the sensitivity to temperature.

TABLE 13 Float Test Index

Sample	Items \ Rubber content	0 %	3 %	5 %	7 %	10%
Sample A	Penetration (25°C, 100 gr., 5″)	69.2	53.1	51.1	41.9	36.3
	Float test (80°C)	60	126	158	200	243
	$P \times F$	4780	6680	8090	8380	8580
	Float test index	69.1	81.8	90.0	91.5	92.5
Sample B	Penetration (25°C, 100 gr., 5″)	82.7	62.7	69.5	82.9	162.3
	$P \times F$	4970	7900	11000	16580	39400
	Float test index	75	89	105	129	198

Slope (Table 9):

In sample A, the grade of the slope was decreased from 0.0170 to 0.110.

Identical results in regard to temperature sensitivity measured by the 5 methods noted above could not be obtained. This is an interesting outcome, and these phenomenon show that the methods of calculation do not always show the practical temperature sensitivity.

Generally, however, the flow properties of rubber blended asphalt were decreased by high temperature and increased by low temperature. These facts indicate the lowering of the temperature sensitivity.

Chap. 3 Dynamic test by a Page impact testing machine

The impact resistance, that is, the toughness of the rubber blended asphalt mortars were measured by a Page impact testing machine. The specimens of asphalt prepared were the same as those described in the above chapter; their physical properties were the same as those described in Chap. 2, sample B. The mineral filler was a limestone dust passing No. 200 sieve. To make the mortar, a natural river sand was used, the fineness and other characteristics of which are reported in Table 14; the fineness modulus was 2.28.

The mixture was composed of 12.5% asphalt, 5% mineral filler and 82.5% natural river sand, while the rubber content in the asphalt was 0, 3, 5, 7 and 10% by weight in the respective samples.

The tests were made at −50°, −40°, −30°, −20°, −10°, 0, 10°, and

20°C. The size of specimen to be tested was determined according to the capacity of the testing machine after the preliminary tests on the selection of the suitable size had been made. Cylinders measuring 35 mm ϕ $\times$ 30 mm were found most suitable. The moulding forms were cut from a steel pipe, and a steel bar was used for moulding the specimen.[1]

TABLE 14 Characteristics of Sand

Specific gravity	2.76
Percent absorption	0.5%
Unit weight	1,752 kg/m^3

Grading

Sieve opening (mm)	Pass percent
1.2	100
0.6	28
0.3	24
0.15	2

The asphalt-rubber blend was prepared by the same method as described in Chap. 2. Prior to mixing, the material for each specimen was heated to about 100 to 110°C; it was then mixed at lowest possible temperature, 120 to 130°C, during 15 to 20 minutes, and then poured into the steel form.

The mixtures in the mould were allowed to cool to 40 to 50°C, then they were pressed under the load intensity of about 200 kg per square cm. Different pressures were used in order to obtain a uniform density. The load intensity was controlled to obtain the same density of about 2.18. The load was applied for about 5 minutes. All specimens removed from the moulds were stored in low temperature room in which the temperature of the specimen was maintained at 0°C until time for the tests.

The temperatures of specimens to be tested at 20°C and 10°C were obtained by immersion in a water bath of constant temperature; 0°C was obtained by mixing of ice and water in low temperature room of 0°C; −20°C and −30°C were obtained by mixing with ice and calcium chloride; −40°C and −50°C were obtained by bath filled with dry-ice, respectively. All temperature under 0°C were secured in a low temperature room.

The Page impact test for test temperatures 20°C and 10°C, was made in a low temperature room of 0°C to 5°C; and in temperatures lower than −10°C, in the low temperature room of −15°C to −20°C.

On measurement of toughness, the height of the drop hammer was increased by 1 cm. for each succeeding blow until rupture of a specimen occurred. The height from which the hammer fell when rupture occurred was taken as the numerical value representing the

TABLE 15 Toughness of rubber

rubber content	Test Temp. 20°C			Test Temp. 10°C			Test Temp. 0°C			Test Temp, −10°C		
	No.	Toughness measured		No.	Toughness measured		No.	Toughness measured		No.	Toughness measured	
		crack	failure		crack	failure		crack	failure		crack	failure
0 %	1	23	30	19	14	18	7	7	9	10	8	9
	2	20	33	20	12	21	8	7	10	11	8	9
	3	22	30	21	14	19	9	9	12	12	8	9
	25	16	—	28	16	26	35	11	16	37	9	10
	26	14	29	29	18	23	36	10	13	38	8	9
	27	17	31	30	15	22	54	9	12	39	6	8
	Aver.	18.6	31.0	Aver.	14.8	21.5	Aver.	9.0	12.0	Aver.	7.8	9.0
3 %	301	16	36	306	12	22	307	12	13	310	7	8
	302	18	32	307	21	28	308	13	16	311	13	15
	303	20	35	320	19	28	309	13	16	312	8	9
	325	15	32	328	22	33	334	14	18	337	8	10
	326	21	35	329	19	27	335	15	19	338	9	11
	327	16	35	330	16	26	336	12	14	339	11	13
							355	13	17			
	Aver.	17.7	34.2	Aver.	18.2	27.3	Aver.	15.3	16.1	Aver.	9.3	11.0
5 %	501	16	32	504	22	33	507	14	16	510	10	11
	502	18	32	505	22	32	508	12	15	511	10	11
	503	20	35	506	16	34	509	12	18	512	12	15
	525	15	30	528	20	34	535	14	22	537	9	11
	526	15	28	529	13	25	536	14	19	538	9	11
	527	19	29	530	17	34	565	12	16	539	12	15
				561	17	31						
	Aver.	17.2	31.0	Aver.	18.1	31.8	Aver.	13.6	18.7	Aver.	10.3	12.3
7 %	701	16	31	704	17	29	707	17	20	710	12	14
	702	16	34	705	17	34	708	13	20	711	12	15
	703	15	26	706	19	33	709	17	19	712	11	12
	725	16	22	729	13	30	734	14	26	737	12	14
	726	13	23	752	17	27	735	13	24	738	11	15
	745	13	28	753	14	31	736	13	22	739	11	16
	746	12	27									
	Aver.	14.4	27.3	Aver.	16.2	30.7	Aver.	14.5	21.8	Aver.	11.5	14.3
10%	102	9	25	106	17	32	107	16	27	110	13	15
	103	14	25	128	15	31	108	18	25	112	13	14
	125	9	20	129	14	30	109	23	31	137	20	30
	126	12	24	130	15	28	134	16	26	138	20	25
	127	8	20	150	17	28	135	16	28	139	20	28
	153	8	24	151	13	29	136	15	30			
	154	9	23	152	17	27						
	Aver.	9.9	24.4	Aver.	15.4	29.3	Aver.	17.3	27.8	Aver.	17.2	22.4

blended asphalt mortar

Test Temp. −20°C			Test Temp. −30°C			Test Temp. −40°C			Test Temp. −50°C		
No.	Toughness measured		No.	Toughness measured		No.	Toughness measured		No.	Toughness measured	
	crack	failure		crack	failure		crack	failure		crack	failure
13	8	10	16	7	8	45	4	5	43	4	5
14	6	8	17	6	7	46	4	5	44	4	5
15	7	10	18	6	8	48	4	5	49	4	5
40	6	7	52	4	5	50	5	5	51	4	4
41	7	8	53	7	7						
42	5	6									
Aver.	6.5	8.2	Aver.	6.0	7.0	Aver.	4.3	5.0	Aver.	4.0	4.8
313	8	9	316	8	9	348	6	6	343	6	7
314	8	10	317	7	8	351	9	9	344	7	7
315	8	9				347	8	8	345	6	6
340	7	8	352	7	7	353	5	6	346	5	5
341	6	7	354	7	7	349	5	6	350	5	6
342	6	7									
Aver.	7.2	8.3	Aver.	7.3	7.8	Aver.	6.6	7.0	Aver.	5.8	6.2
513	8	10	516	9	9	546	6	7	543	7	7
514	13	14	517	11	13	548	8	8	545	6	7
515	8	10	518	10	12	560	8	9	549	6	7
540	8	8	562	9	10				564	5	6
541	8	9	563	8	8						
542	8	9									
Aver.	8.8	10.0	Aver.	9.4	10.4	Aver.	7.3	8.0	Aver.	6.0	6.8
713	13	14	716	10	12	747	8	9	743	7	8
714	13	15	717	13	14	750	9	10	744	7	7
715	11	13	718	12	15				748	6	7
740	9	10	749	9	10						
741	10	11	751	9	9						
742	11	13									
Aver.	11.2	12.7	Aver.	10.6	12.0	Aver.	8.5	9.5	Aver.	6.6	7.3
113	17	18	116	15	16	147	10	11	143	8	9
114	15	18	117	16	17	148	11	12	144	9	10
115	17	17	118	15	16						
140	14	17	146	12	13						
141	14	15	149	12	13						
142	13	17									
Aver.	15.0	17.0	Aver.	14.0	15.0	Aver.	10.5	11.5	Aver.	7.5	9.5

Fig. 5—Fig. 10 Relation between toughness and test temperature of rubber blended asphalt mortar.

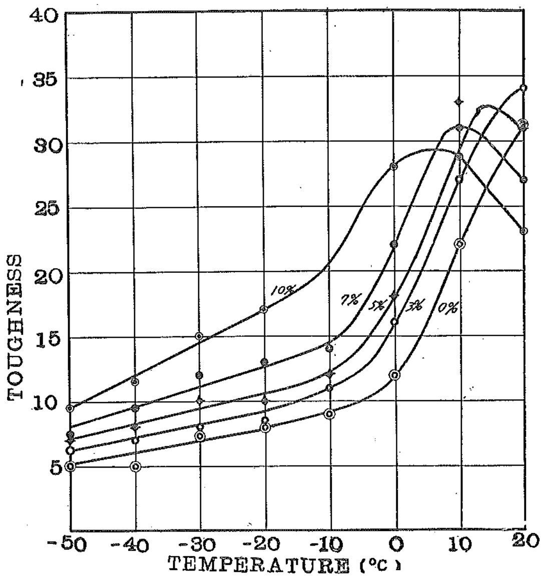


Fig. 5.

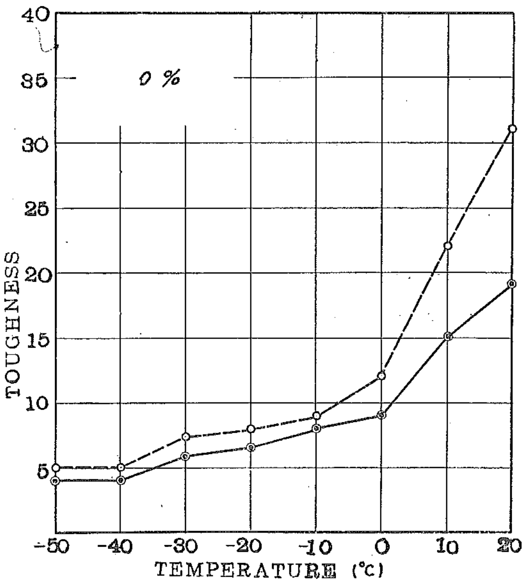
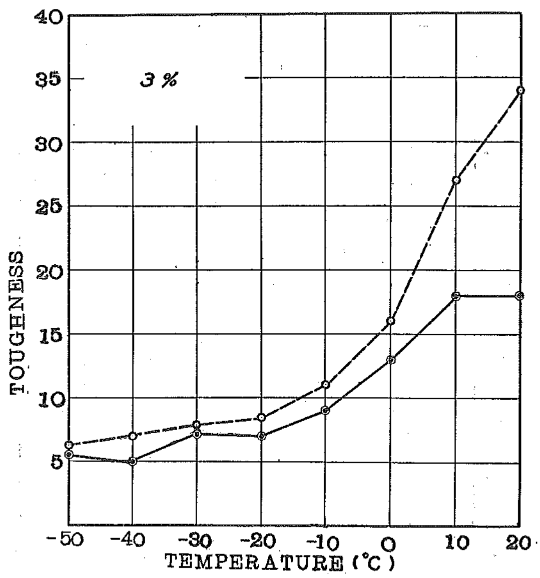
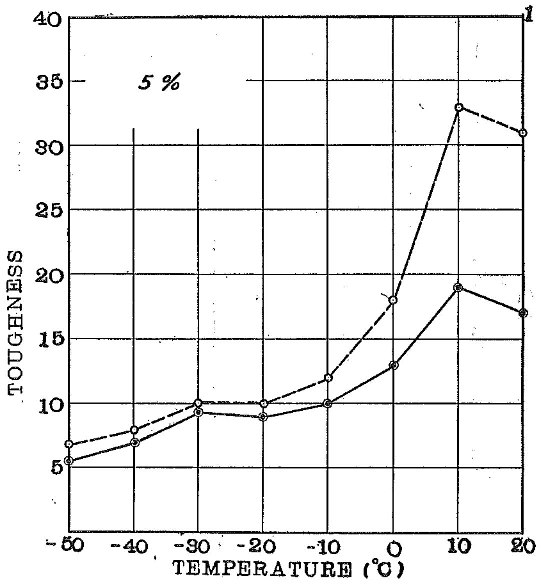


Fig. 6.



40
35
30
25
20
15
10
5
3 %
TOUGHNESS
-50
-40
-30
-20
-10
0
10
20
TEMPERATURE (°C)

Fig. 7.



40
35
30
25
20
15
10
5
5 %
TOUGHNESS
-50
-40
-30
-20
-10
0
10
20
TEMPERATURE (°C)

Fig. 8.

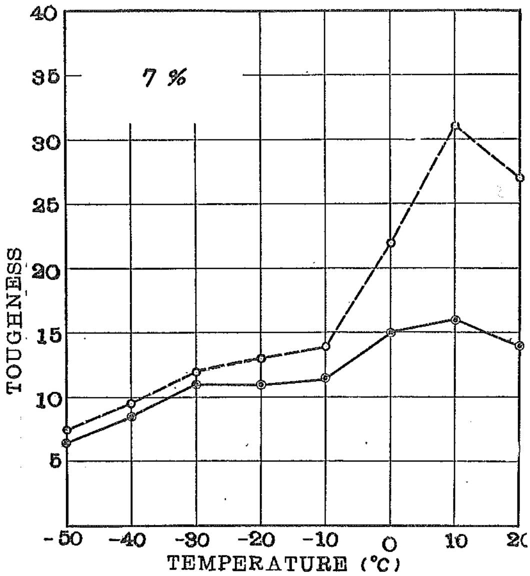

7 %
TOUGHNESS
TEMPERATURE (°C)
40
35
30
25
20
15
10
5
-50
-40
-30
-20
-10
0
10
20

Fig. 9.

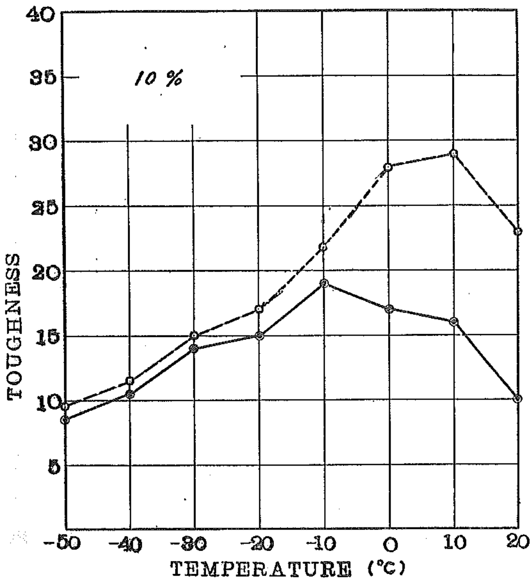

10 %
TOUGHNESS
TEMPERATURE (°C)
40
35
30
25
20
15
10
5
-50
-40
-30
-20
-10
0
10
20

Fig. 10.

toughness of the material under test. At low temperature, a failure of the specimens was clearly recognized, if they broke into two or three pieces, but at comparatively high temperature, judgement of the occurrance of failure was rather difficult.

Test result:

The relations of toughness and temperature, are shown in Fig. 5 to Fig. 10 and in Table 15. In these figures, a dotted line shows the failure of the specimens, and a full line indicates the point at which crack was formed. Fig. 11 shows the relation of rubber content and toughness at each temperature.

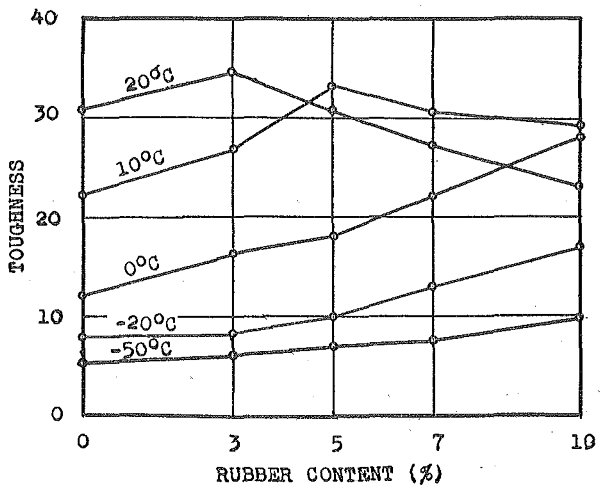


Fig. 11 Relation between toughness and rubber content of rubber blended asphalt mortar.

(a) The toughness measured by a Page impact testing machine was generally reduced in accordance with lowering of temperature, as shown in the figures; within some temperature ranges, these rates of reduction of brittleness showed a parabolic relation at higher than −20°C, and straight line relation at lower than −20°C. However the general shapes of the relationship between temperature and toughness were the same in each blend as shown in Fig. 5. There were considerable differences in the absolute values of the toughness in each blend of the mixtures. Generally their toughness was decreased in accordance with lowering of temperature.

(b) The mixtures generally showed visco-liquid properties at higher than about 0°C, but the temperature in the mixture at which the maximum toughness was attained, was different in each blend, these temperatures depend on rubber content. The relation of maximum toughness and temperature is a regular relation.

(c) The values of the tougness ratios were 2.50 in 0%, 2.30 in 3%, 2.34 in 5%, 2.29 in 7% and 2.42 in 10% rubber mixtures, respectively. Thus it is seen that there were no considerable differences in values of the toughness ratios. These facts show that the rubber addition brings increases of toughness, although the rubber addition does not much affect sensitivity.

(d) According to the proportion of rubber content in an asphalt, the toughness increased within a certain range of temperature but this regular relation was not found at higher than 0°C.

Chap. 4 Dynamic modulus of elasticity of rubber blended asphalt mortar

The dynamic modulus of elasticity of rubber blended asphalt mortar was measured with a sonic apparatus. Test temperatures were 20°C, 10°C, 0°C, −10°C, −20°C, and −30°C; the compositions were the same as those for the impact tests.

The dynamic modulus of elasticity was calculated from the fundamental transverse frequency, weight and dimensions of test specimens by the following equation:

$$E = C \frac{4l}{S} Wf^2$$

where C: constant.
E: dynamic modulus of elasticity in kg per sq. cm.
W: weight of specimen in grams.
l: length of specimen in cm.
S: cross sectional area of test specimen in sq. cm.
f: frequency in cycle per second.

The dynamic modulus of elasticity was obtained on three 6 by 6 by 25 cm. bars of each sort of composition.

Table 16 shows the results of this measurement. Fig. 12 to Fig. 17 show the relation between dynamic modulus of elasticity and rubber content. Fig. 18 to Fig. 22 show the relation between dynamic modulus of elasticity and test temperature.

TABLE 16 Dynamic Modulus of Rubber Blended Asphalt Mixture ($\times 10^4$ kg/cm^2)

Rubber content (%)	Test temperature (°C)	Specimen No. 1		Specimen No. 2		Specimen No. 3		Aver.
		Cycles of frequency	Dynamic Young's Modulus	Cycles of frequency	Dynamic Young's Modulus	Cycles of frequency	Dynamic Young's Modulus	Dynamic Young's Modulus
0	−30	5,600	16.30	5,600	16.75	5,600	16.50	16.52
	−20	5,300	14.60	5,300	15.02	5,180	14.15	14.59
	−10	5,300	14.60	5,280	14.90	5,300	14.77	14.76
	0	5,450	15.45	5,300	15.02	5,300	14.77	15.08
	10	5,200	14.08	5,300	15.02	5,300	14.77	14.62
	20	5,000	13.00	5,100	13.90	5,000	13.15	13.35
3	−30	5,400	15.35	5,400	15.25	5,400	15.40	15.33
	−20	5,360	15.15	5,340	14.90	5,300	15.10	15.05
	−10	5,360	15.15	5,300	14.70	5,350	15.15	15.00
	0	5,200	14.25	5,400	15.25	5,350	15.15	14.89
	10	5,000	13.15	5,000	13.10	4,900	12.65	12.97
	20	5,200	14.25	5,100	13.60	5,200	14.25	14.03
5	−30	5,450	15.90	5,470	16.00	5,450	15.90	15.93
	−20	5,300	15.05	5,350	15.30	5,380	15.50	15.28
	−10	5,300	15.05	5,300	15.05	5,300	15.05	15.05
	0	5,300	15.05	5,300	15.05	5,300	15.05	15.05
	10	5,100	13.90	5,200	14.50	5,200	14.50	14.30
	20	5,100	13.90	5,000	13.40	5,200	14.50	13.93
7	−30	5,440	15.75	5,520	16.15	5,500	16.15	16.02
	−20	5,350	15.20	5,300	14.95	5,300	15.00	15.02
	−10	5,300	14.95	5,320	15.00	5,300	15.00	14.98
	0	5,400	15 50	5,400	15.50	5,300	15.00	15.33
	10	5,000	13.30	5,100	13.80	5,200	14.45	13.85
	20	4,900	12.75	5,300	14.95	5,300	15.00	14.23
10	−30	5,520	16.20	5,500	16.05	5,460	15.75	16.00
	−20	5,260	14.75	5,320	15.00	5,290	14.80	14.85
	−10	5,300	14.95	5,300	14.90	5,300	14.85	14.90
	0	5,300	14.95	5,250	14.60	5,300	14.85	14.80
	10	5,100	13.85	5,100	13.80	5,000	13.25	13.63
	20	5,300	14.95	5,100	13.80	5,100	13.85	14.20

Fig. 12—Fig. 17 Relation between dynamic modulus of elasticity and rubber content of rubber blended asphalt mortar.

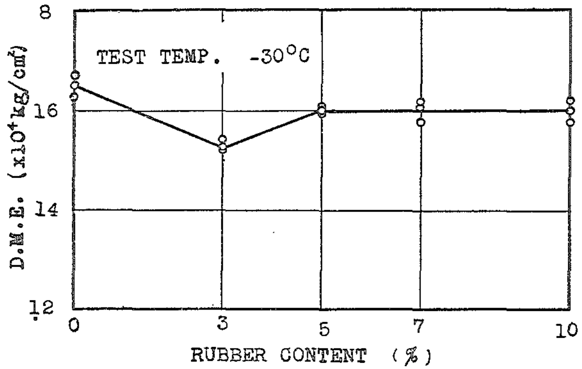


Fig. 12.

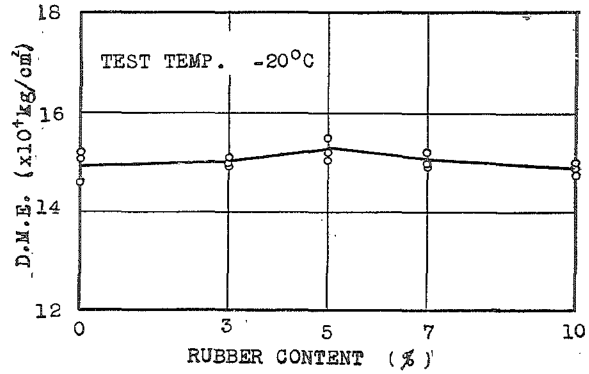


Fig. 13.

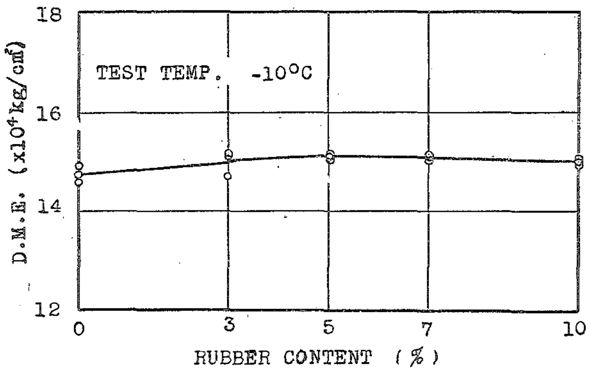


Fig. 14.

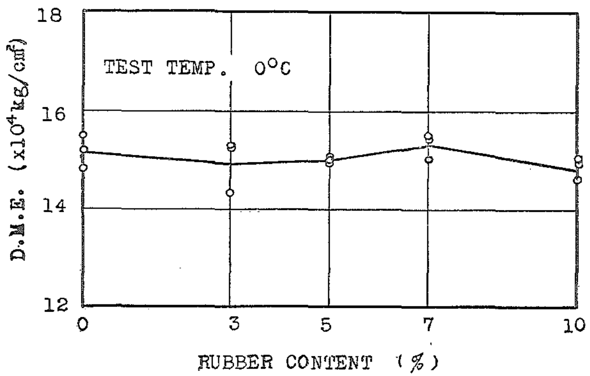


Fig. 15.

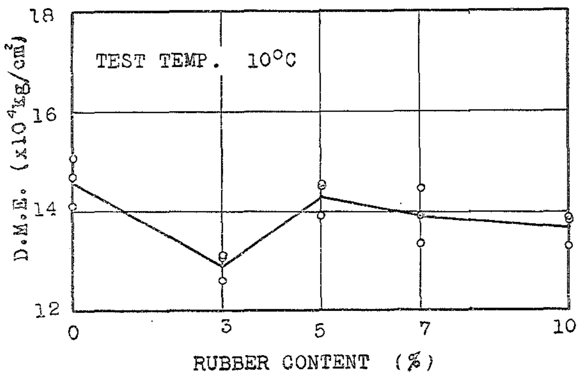


Fig. 16.

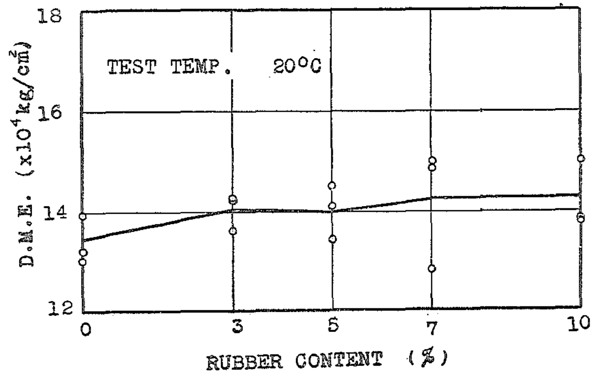


Fig. 17.

Fig. 18—Fig. 22 Relation between dynamic modulus of elasticity and test temperature of rubber blended asphalt mortar.

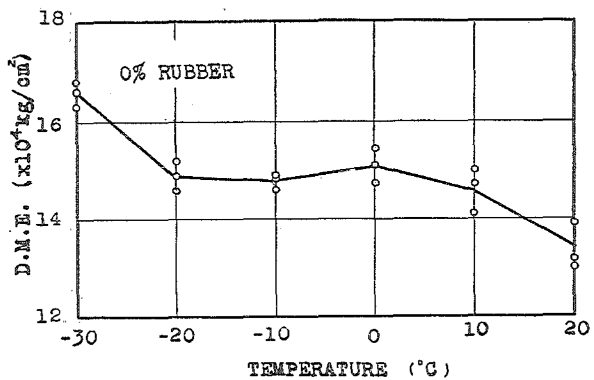


Fig. 18.

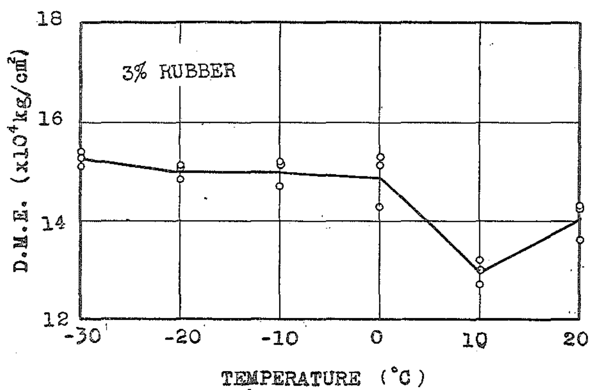


Fig. 19.

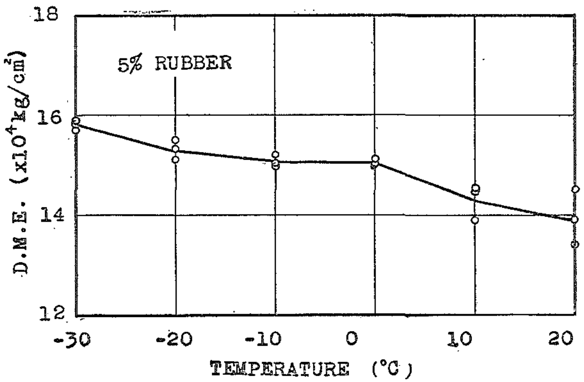


Fig. 20.

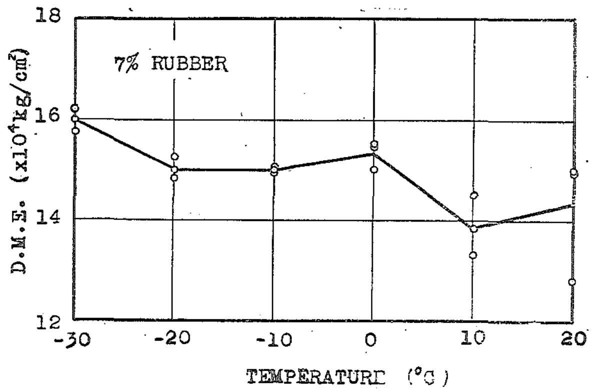


Fig. 21.

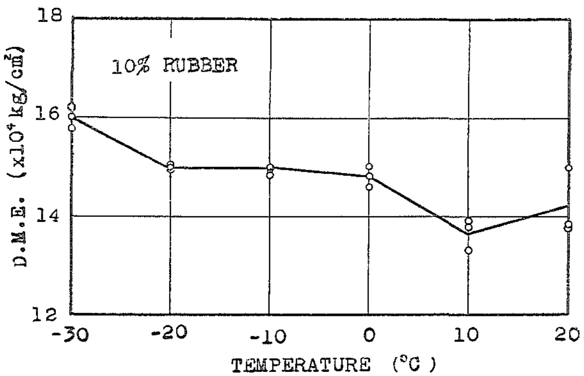


Fig. 22.

In both relations, no remarkable differences were found. To generalize, it may be said that the amount of rubber added does not cause any remarkable differences in the elasticity of rubber blended asphalt. If the sonic apparatus were more improved, more significant results in elastic property of rubber blended asphalt might be obtained.

Chap. 5 Application of test results

As for the practical employment of rubber blended asphalt mixtures, it was found that such mixtures have high resistance to impact load. The abrasion of asphalt road is caused by the beating action of tire chains attached to pneumatic tires to prevent slipping in winter. This beating action is regarded as an impact load or shock. Rubber blended asphalt may have high resistance to the abrasion against its surface.

To make a practical application of the laboratory tests, surface dressings of rubber blended asphalt mortar, and various paint coats were laid with the cooperation of the Hokkaido Development Bureau in July to August 1954, near the foot of a -6% longitudinal slope of about 300 meters length at Wattsu in the test road section of National Highway No. 36 between Sapporo city and Chitose Air Port.

This field test employed the following 4 types of rubber blended asphalt mixtures. Two of them were wearing courses made of an asphalt mortar of 1.5 cm. thickness; the other two were paint coats including 40% of mineral filler and rubber powder. The rubber blended asphalt mortar was prepared with a composition of 12% asphalt having 200 penetration value, 4.8% mineral filler and 83.2% fine natural river sand. "Mealorub" blended was 3 and 5% of the asphalt. The rubber-asphalt blends were made by the pre-blending method; the heating period was about 20 hours at 130°C. Photograph-1 shows the rubber blended asphalt cement.

The base course was made of a penetration asphalt macadam of 7 cm. thickness. Photograph-2 shows the placing and rolling of rubber blended asphalt mortar in test road section.

The paint coat surface dressing blended with rubber powder were laid on the asphalt concrete by the conventional method used in applying a seal coat.

Before the preparation of the test road, this section had been very extensively damaged. It was subjected to the most severe conditions caused by the passage of many heavy, high speed vehicles, during a cold winter.

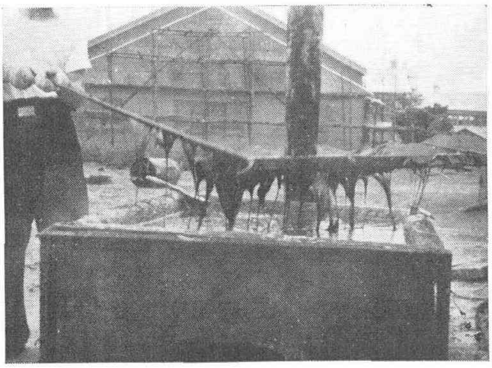


Photo 1. Rubber blended asphalt cement in a kettle.

Photo 2. Placing and rolling of rubber blended asphalt mortar in the test road section.

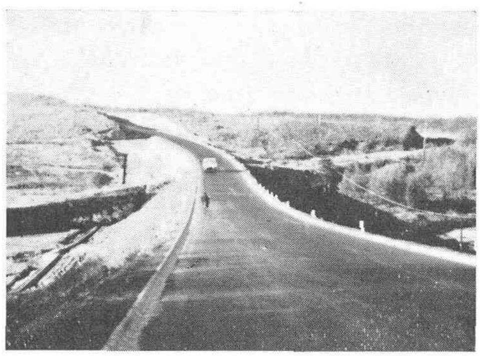


Photo 3. General view of test road at Wattsu between Sapporo city and Chitose Air port, Hokkaido.

Photo 4. Sign-board showing test section.

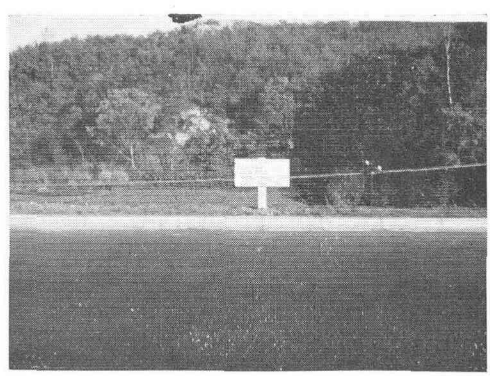


Photo 5. Sign-board showing paint coat surface with rubber.

As to the result of this field test, the rubber blended asphalt mortar surface remained in good conditions; there were no damages by the beating actions of the tire chains, or other abrasions, in spite of the steep slope of -6%. On the other hand there remained absolutely no trace of the paint coats on that slope. The asphalt concrete, topeka and the other paint coats without rubber were damaged even on the level section. Sections where the paint coats remained on the surface course, suffered from high slipperiness due to the paint coat, and now this liquid paint coat asphalt needs the spraying of fine sand to prevent flowing and the slipping of vehicles.

Chap. 6 Summary and conclusions

As the result of these tests on rubber blended asphalt and asphalt mixtures, the following conclusions were reached:

1) Penetration was affected by the rubber addition; there were remarkable differences in penetration of the rubber blended specimens which were made in different heating periods.

In sample A heated and stirred for a short period of about 2 hours, the penetration value was decreased proportionally to increase of rubber content; reversely in sample B heated and stirred for a long period of about 20 hours, the penetration was increased proportionally to increase of rubber content. Penetration at temperature 0°C was increased by the rubber addition, but the relations between penetration and the rubber content are similar to that at 25°C. But it was sure that the penetration at low temperture was increased. The tendency of increase or decrease of the penetration in relation to the rubber content at each temperature was quite similar. (Fig. 1, and Table 1 to Table 4).

2) Softening point of rubber blended asphalt showed an increase, and the relation between the rubber content and the softening point was nearly in a straight line relation. (Table 5, Fig. 2)

3) Ductility of rubber blended asphalt was remarkablly decreased according to the rubber content. This tendency was clear in 3% rubber addition, but there were no considerable differences in rubber content higher than about 5%; this tendency was regarded to indicate that the ductility was too small to show the true character of ductility

4) There were no considerable changes in specific gravity, flash point and burning point. Flash point and burning point were slightly increased by the addition of rubber. These increases were proportional to the rubber content.

5) Identical results were not obtained by the 5 methods which were employed to find the temperature sensitivity of rubber blended asphalt.

By the use of some methods the asphalt showed increase in sensitivity, and by other method, it showed decrease.

Accordingly, it must be said that these 5 methods do not always show the true sensitivity. Then it is necessary to establish a calculation method for obtaining temperature sensitivity.

But, generally, the sensitivity was improved because the flow was decreased and the penetration was increased or slightly decreased; the increase of softening point was remarkable. (Table 9 to Table 13)

6) The shock resistance of rubber blended asphalt mixtures was improved. The toughness of rubber blended asphalt mixtures was measured by a Page impact testing machine, and toughness value was found to be increased by the rubber addition at all test temperatures from 20°C to −50°C. The rate of increase of toughness is proportional to rubber content.

The toughness of 10% rubber content mixture reached twice the value of that of 0% rubber mixture at all test temperatures. The toughness of these mixtures was decreased according to lowering of temperature. This rate of decrease was proportional at temperatures lower than about −10°C., and showed a parabolic relation at higher than −10°C. At higher tempertures, for the specimens, in which flow occurred, it was not possible to determine exactly their toughness, and curves showing the relation between maximum toughness and temperature had an envelope of a straight line.

7) Dynamic modulus of elasticity of specimens was measured by a sonic device, but there were no considerable changes in values of dynamic modulus of elasticity in each specimen. It seems needful to reconstruct the pick-up circuit and mechanisms of the pick-up.

8) As to the result of the tests on the test road, rubber blended asphalt mortar showed the high resistance to abrasion caused by the heavy and special traffics in winter, while the paint coat with rubber was severely ravelled off. In the summer of this year (1955), although the temperature of the asphalt pavement reached to 45°C. to 50°C. and all other pavements have shown extensive flowing, the flow and slipperiness are not found in this test section composed from rubber blended asphalt mortar with either 3% or 5% of natural rubber. Now this section is in the best condition.

Future Development:

The authors are now investigating the rheological behavior of the asphalt mixtures using the sonic device; the visco-elastic properties of asphalt mixtures will be found by measuring amplitude of vibration, damping and its period. The authors are also now testing the uses and the properties of reclaimed rubber.

Acknowledgement

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