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

Experimental Researches on Reclaimed and Natural Rubber Blended Asphalt and Asphalt Mixtures

By

Chūzo ITAKURA and Teruo SUGAWARA

(Received June 30, 1956)

CONTENTS

Synopsis

In recent years, the use of the several types of the rubber asphalt roads has been promoted intensively. The pricipal advantages causing the addition of rubber are lower susceptibility to temperature change, the occurrence of less ravelling and abrasion by cold-weather traffic, and greater resistance to skidding.

Investigations were made at low temperatures down to −40°C on the effects of the inclusion of various sorts rubber, natural rubber powder "Mealorub", and two kinds of reclaimed rubber powder, with the petroleum asphalt used in paving mixtures. These tests were concerned with the changes of physical properties that occur when the various sorts of rubber powder were blended with asphalt.

This report shows that the various rubber powders affect the physical properties of a given asphalt to cause it to become more stable.

In general, the impact resistance was increased by the addition of the rubber, the rate of improvement of the shock resistance at low temperature was varied by the kind of the rubber added, while the shock resistance was varied by heating and mixing time. Softening

point and viscosity was increased by the addition of rubber, and ductility at low temperature was increased by the addition of natural rubber.

As comparison of the rate of improvement of these characteristics, natural rubber showed best results in respect to all characteristics.

Chap. 1 General description

In cold weather bituminous pavements are easily damaged. The causes of damage are low temperature, the special traffic conditions, changes in the physical properties of the material, and the freezing and thawing actions occurring in the presence of water. Accordingly, in recent years, much attention has been given to improvement of the asphalt mixtures, in Hokkaido, Japan. Prior to the present investigation, tests concerning impact resistance, temperature sensitivity and elastic properties of the conventional asphalt mixtures had been made by the authors. As to results of those tests, it may be said, in general, that the characteristics of the bituminous mixtures depend upon the charactor of the asphalt used in the mixtures; there were some differences of the values of the impact resistance in the mixtures made with various amounts and kinds of asphalts, but there was no remarkable variation in temperature sensitivity or in the slope of log. toughness-temperature relation. If it is desired to alter these characteristics, the asphalt itself should be improved.

Attention has also been directed, in recent years, to the experimental uses of the rubber blended asphalt pavements.

Claims have been made that the use of rubber extends the life of the bituminous pavements, gives them more elastic properties at high temperature, increase the resistance to shock at low temperature, decreases their slipperiness, promotes resistance to water action, and reduces maintenance costs.

These several weak points in the conventional flexible pavement need very much to be improved.

Many experimental rubber-asphalt pavement sections have been built to determine under actual service conditions, the comparative degree of progressive alteration in properties of the rubber-asphalt mixtures that occurs with age.

Experimental sections of various surface dressings, composed of sand, filler, petroleum asphalt, and a small amount of natural rubber powder "Mealorub", were laid down on asphalt concrete aiming to improve the shock resistance in cold weather, in Hokkaido, Japan. Also experimental researches on several characteristics of rubber-asphalt blend and rubber blended asphalt mortars were made by the authors. As a result of these tests, it was found that the rubber blended asphalt has high resistance to shock at low temperatures.

In view of these considerations, some investigation concerning the shock resistance was carried on and temperature sensitivity tests were made again using three kinds of rubber: one natural rubber powder "Mealorub" and two kinds of reclaimed rubber. In these tests special attention was paid to the impact resistance at low temperatures, and effects of amount of rubber, and of the heating time during blending of asphalt and rubber. In the present investigation, the range of low temperatures was widened to as low a point as −40°C. The impact resistance was obtained by using a Page impact testing machine.

The amount of rubber used for these tests was 3, 5, 7 and 10% in the blend with natural rubber powder "Mealorub", 5, 10, 20% and 30% in the blends with reclaimed rubber powder "A", "N". The asphalt used was a kind of straight asphalt produced from Akita, Japan.

Chap. 2 Properties of rubber blended asphalt

1. Materials.

asphalt: the properties of the asphalt used are as follows:

specific gravity	25C°/25C°	1.109
penetration	25°C, 100 gr., 5 sec.	120
	0°C, 100 gr., 5 sec.	10
	0°C, 200 gr., 60 sec.	31
ductility	25°C, more than	140
softening point	°C.	40
float test	sec.	80
flash point	°C.	273
burning point	°C.	315

rubber:

1. Natural rubber powder "Mealorub".
2. Reclaimed rubber powder "A" ground pneumatic tire scrap. The principal ingredients of this rubber are as follows:

rubber content	60%
carbon black	10%
zinc white	5%
others	25%

fineness: all particles pass 30 mesh screen.
specific gravity: 1.2.

3. Reclaimed rubber powder "N" ground scrap of boots and rubber shoes.
   The principal ingredients of this rubber are as follows:

rubber content	40%
reclaimed rubber	20%
calcium carbonate	20%
zinc white	5%
pine tar	several %

fineness: all particles pass 60 mesh screen.
specific gravity: 1.3

2. Test methods.

Blends of the three rubbers with one asphalt were prepared to determine the effect of the rubber content and of the heating time on the test characteristics. In order to determine the effect of different amounts of the rubber on the properties of the blends, on the basis of the preliminary study, 3, 5, 7 and 10% of natural rubber powder "Mealorub", and 5, 10, 20 and 30% of reclaimed rubber powder "A", "N" were added to the asphalt.

The blends were prepared by mixing the asphalt and rubber at 120°C to 130°C for 20 hours in the oven. This blending time was determined after preliminary tests; in the preliminary tests considerable changes on the blends occurred in many of the blends during about 5 hours. In order to determine the rate of the changes of characteristics of the blend, the specimens were removed at various intervals such as after 0, 2, 5, 7, 10 and 20 hours of heating.

3. Effect on penetration.

Change occurring in the rubber-asphalt blends during 20 hours heating and mixing period, are shown Figs. 1~3. The effect of heating on the penetration of the asphalt without rubber, also, is shown.

Figs. 1~3 show the relations among the amount of the rubber, the penetration and the heating time respectively. In the first stage of heating, in general, the addition of the rubber to the asphalt resulted in a decrease in penetration. This tendency was remarkable for the blends with a large amount of rubber in all blends.

The increase of the heating time brought the increase of the penetration. It is of interest to note the wide difference in the in-

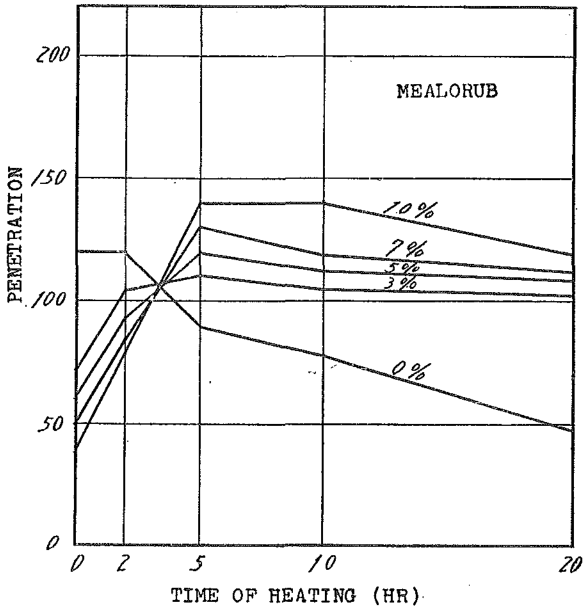


Fig. 1. Relation between penetration (25°C, 100 gr., 5 sec.) and heating time of the blend with natural rubber powder "Mealorub".

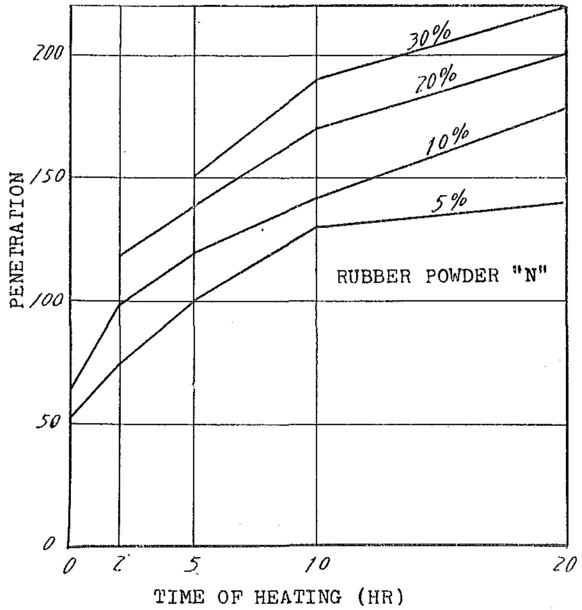


Fig. 2. Relation between penetration (25°C, 100 gr., 5 sec.) and heating time of the blend with reclaimed rubber "N".

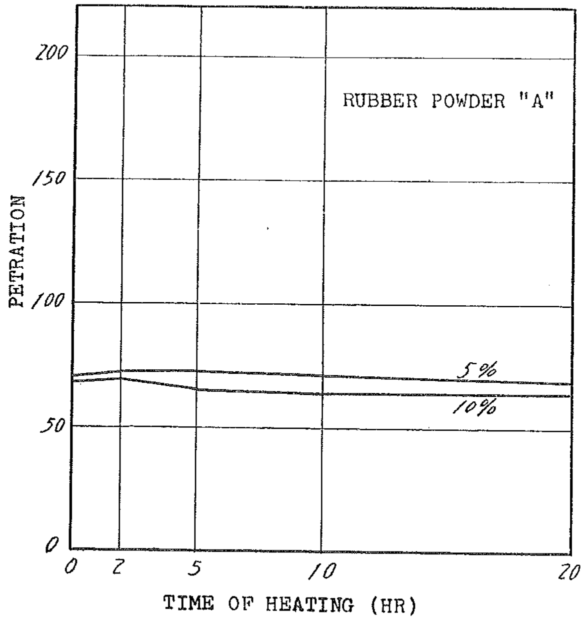


Fig. 3. Relation between penetration (25°C, 100 gr., 5 sec.) and heating time of the blend with reclaimed rubber "A".

crease of the penetration caused by the heating time and various kinds of the rubber. When the rubber content of the blends was increased, there was a much greater rise in the penetration for Mealorub-asphalt blend. After 5 hours heating the penetration was decreased. The maximum increase occurred at about 5 hours, for all amounts of Mealorub. This maximum penetration was 140 on 10% addition, 130 on 7%, 120 on 5% and 110 on 3%. In the blends with reclaimed rubber "N", the penetration increased proportionally with the increase of heating time, and did not attain maximum value within 20 hours heating. For that length of heating, the penetration increased with the increase of the amount of rubber, and the penetration of the blends including 30% rubber reached to 210; this value is a remarkable increase. The blends with rubber powder "A" did not show marked difference in penetration within 20 hours heating for all amounts of rubber; the penetration of 10% mix is lower than that of 5% at all heating times.

4. Effect on ductility.

Ductility tests were made on the original asphalt and the various rubber-asphalt blends after 2, 5, 10, 20 hours heating, at 25°C for the two kinds of reclaimed rubber-asphalt blends, and 25°C and 0°C for natural rubber-asphalt blend, respectively.

In the first period of heating and mixing, in general, the addition of rubber to the ashalt caused a reduction in ductility. It is probable that the ductility of many of the blends was affected by the presence of free particles of rubber powder.

For the blends with natural rubber powder, the ductility does not measured due to the fact that their ductility was beyond the capacity of the ductility machine, then the test temperature was brought to 0°C.

The largest increase in ductility appeared in blends containing natural rubber powder. The addition of rubber "A" brought remarkable reduction of ductility.

For all blends except one with reclaimed rubber powder "A", the ductility was increased with the increase of the heating time within 20 hours of heating. For rubber "A", the changes in ductility due to increase of heating time were a mere trace.

Figs. 4 ~ 6 show the effect on ductility of the blending of rubber with asphalt.

The effect of temperature on natural rubber-asphalt was also observed. The effect of temperature on ductility of the original asphalt and of the natural rubber-asphalt blends, was compared.

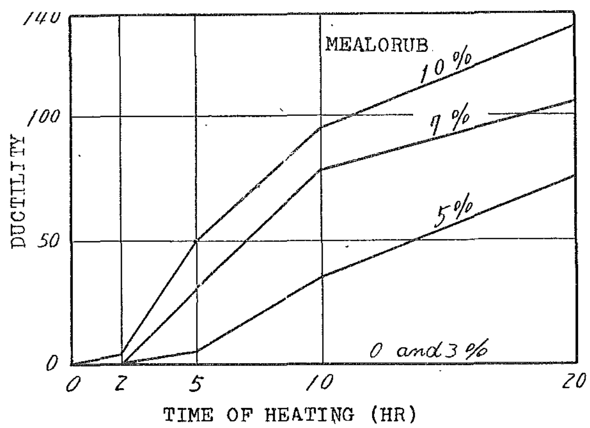


Fig. 4. Relation between ductility at 0°C and heating time of the blend with natural rubber powder "Mealorub".

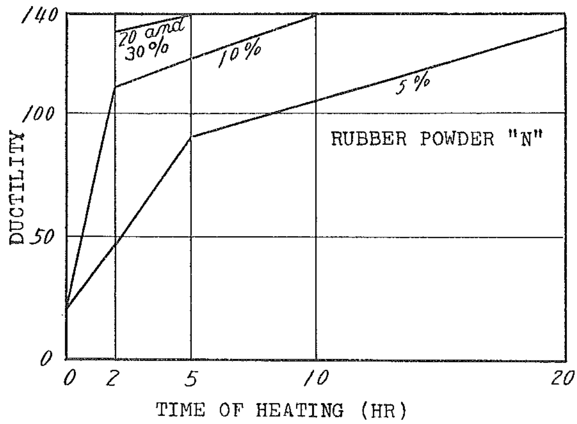


Fig. 5. Relation between ductility at 25°C and heating time of the blend with reclaimed rubber powder "N".

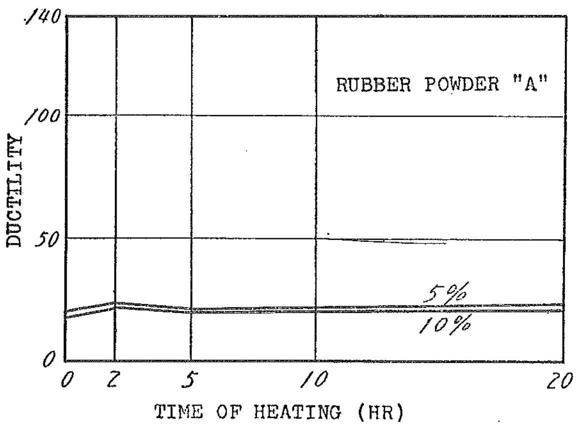


Fig. 6. Relation between ductility and heating time of the blend with reclaimed rubber "A".

The original asphalt and rubber-asphalt blend with 3% of rubber have zero ductility at 20 hours heating, but the blends with 5% or more rubber show remarkable increase in ductility at 0°C.

It was ascertained that the low temperature ductility also was increased with elongation of heating time. These findings indicate that the addition of rubber definitely improves the low temperature ductility, and also that the addition of rubber brings desirable changes in principles governing the use of asphalt in localities where low temperatures are experienced.

5. Effect on float test.

In order to determine the relation of viscosity and temperature, float tests were made on some blends.

There was a very wide range of change in float tests of the various blends during a 20 hour period. In general, the addition of the rubber brings increase in the float test value, and also the increase in the amount of the rubber yields an increase (decrease of softeness) of float test value.

For all blends, the maximum value was reached at about 2 hours, while after 2 hours heating all blends showed decrease in float test value during 20 hours.

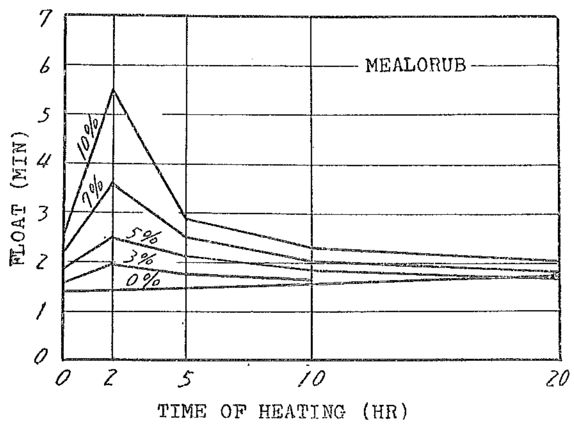


Fig. 7. Relation between float test value and heating time on the blend with natural rubber powder "Mealorub".

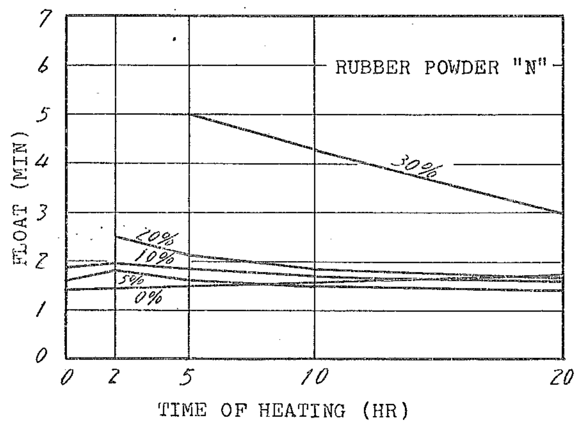


Fig. 8. Relation between float test value and heating time on the blend with reclaimed rubber powder "N".

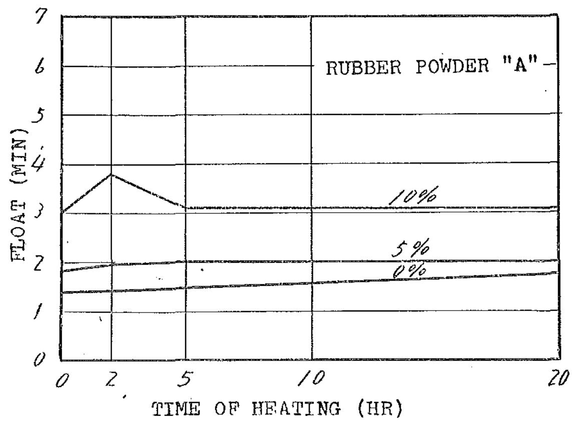


Fig. 9. Relation between float test value and heating time on the blend with reclaimed rubber powder "A".

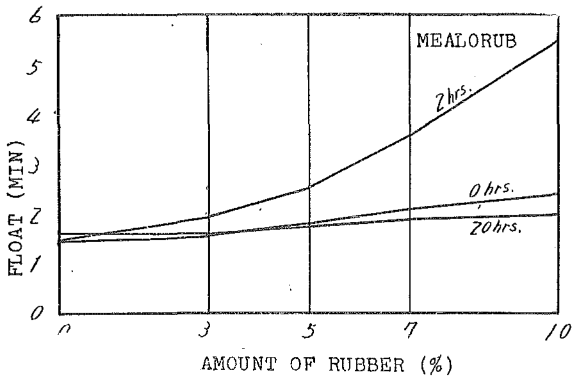


Fig. 10. Relation between float test value and the amount of rubber on the blend with natural rubber powder "Mealorub".

Figs. 7~9 show the effects of the heating time and the amount of rubber on float test. Figs. 10~12 show the relation between the float test value and the amount of the rubber.

6. Softening point.

The tendency in changes in softening point caused by the addition of all kinds of rubber samples were the same as in the float test.

Figs. 13~15 show the relation between the heating time and softening point. Float tests indicate that the addition of rubber improves the properties of asphalt at high temperature such as may occur in the pavement.

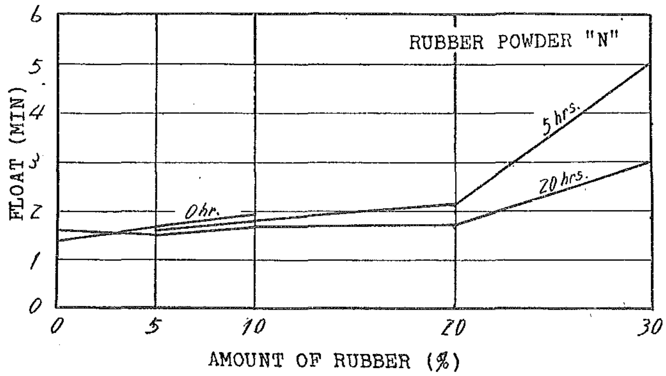


Fig. 11. Relation between float test value and the amount of rubber on the blend with reclaimed rubber "N".

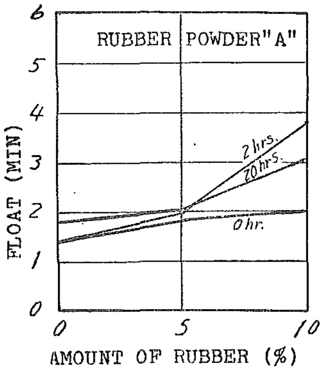


Fig. 12. Relation between float test and the amount of rubber on the blend with reclaimed rubber "A".

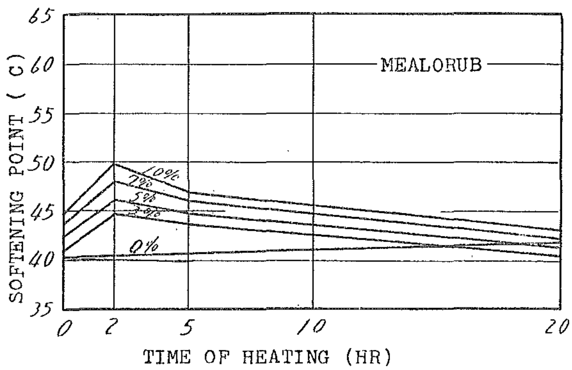


Fig. 13. Relation between softening point and the heating time on the blend with natural rubber powder "Mealorub".

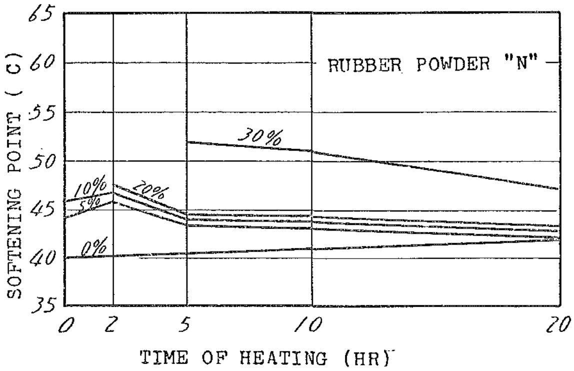


Fig. 14. Relation between softening point and the heating time on the blend with reclaimed rubber powder "N".

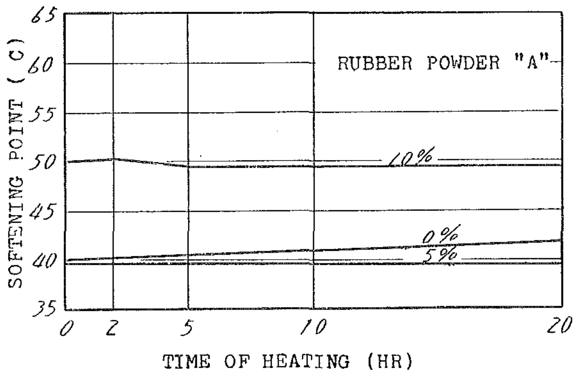


Fig. 15. Relation between float test value and the amount of rubber on the blend with reclaimed rubber "A".

7. Temperature sensitivity of rubber blended asphalt.

Many investigations have shown that the addition of rubber reduces the susceptibility of the asphalt to changes in temperatures. A previous study by J. Ph. Pheiffer 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 temperature sensitivity of an asphalt based on the ratios among 2 or 3 points of the penetration. In these tests, the calculation of a susceptibility factor (S. F.) was based upon the relationship:

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

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 at 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 asphalt is 800 at the softening point; then it is needful to get the true sensitivity by a penetration measurement.

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:

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

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 :

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

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

e. conclusion.

The values of temperature sensitivity as calculated by the above 5 methods, respectively, are shown in tables 1~3.

TABLE 1. Susceptibility of natural-rubber-asphalt blend. (Mealorub)

Amount of rubber (%)	heating time (hrs)	S. F.	Slope	P. T. S.	P. I.	F. I.
0	0	3.90	0.0245	0.0293	− 1.75	97.6
	2	4.10	0.0250	0.0305	− 1.99	97.1
	5	4.00	0.0262	0.0347	− 2.72	87.4
	10	4.50	0.0347	0.0310	− 2.08	79.5
	20	3.84	0.0373	0.0377	− 3.17	72.3
3	0	2.43	0.0213	0.0359	− 3.06	80.6
	2	2.73	0.0233	0.0240	− 0.85	103.5
	5	4.04	0.0268	0.0244	− 1.28	106.3
	10	5.20	0.0293	0.0264	− 1.11	97.8
	20	4.81	0.0311	0.0299	− 2.30	95.9
5	0	2.27	0.0209	0.0359	− 2.91	78.8
	2	3.03	0.0238	0.0240	− 0.51	118.7
	5	3.87	0.0261	0.0244	− 0.61	116.4
	10	4.86	0.0281	0.0264	− 1.11	104.7
	20	4.78	0.0283	0.0299	− 1.87	103.3
7	0	2.04	0.0188	0.0362	− 2.95	77.6
	2	3.00	0.0236	0.0235	− 0.37	131.4
	5	3.71	0.0269	0.0213	0.28	134.9
	10	4.73	0.0276	0.0235	− 0.37	115.7
	20	4.27	0.0267	0.0275	− 1.37	107.4
10	0	2.05	0.0198	0.0376	− 3.16	74.7
	2	3.30	0.0217	0.0227	− 0.14	157.6
	5	3.57	0.0345	—	—	155.5
	10	4.64	0.0264	0.0208	0.45	136.5
	20	3.80	0.0263	0.0251	− 0.80	120.0

TABLE 2. Susceptibility of reclaimed rubber "N"-asphalt blend.

Amount of rubber (%)	heating time (hrs)	S. F.	Slope	P. T. S.	P. I.	F. I.
5	0	4.73	0.0247	0.0343	− 2.66	71.7
	2	4.41	0.0290	0.0269	− 2.23	90.4
	5	4.40	0.0300	0.0270	− 1.25	98.5
	10	4.31	0.0314	0.0245	− 0.64	109.9
	20	3.89	0.0304	0.0250	− 0.77	113.5
10	0	3.53	0.0289	0.0295	− 1.79	81.6
	2	4.36	0.0288	0.0229	− 0.20	107.9
	5	4.45	0.0281	0.0241	− 0.53	115.4
	10	4.11	0.0292	0.0219	0.10	122.9
	20	4.44	0.0310	0.0198	0.79	135.5
20	0	—	—	—	—	—
	2	3.22	0.0286	0.0204	0.58	132.2
	5	3.31	0.0272	0.0215	0.22	129.4
	10	3.61	0.0273	0.0191	1.03	134.8
	20	3.74	0.0280	0.0178	1.53	143.2
30	0	—	—	—	—	—
	2	—	—	—	—	—
	5	2.78	0.0244	0.0149	2.39	214.2
	10	3.02	0.0246	0.0131	3.76	216.2
	20	3.20	0.0249	0.0141	3.64	199.5

TABLE 3. Susceptibility of reclaimed-rubber "A"-asphalt blend.

Amount of rubber (%)	heating time (hrs)	S. F.	Slope	P. T. S.	P. I.	F. I.
5	0	2.50	0.0228	0.0301	− 1.91	87.2
	2	2.64	0.0215	0.0298	− 1.85	91.0
	5	2.84	0.0256	0.0300	− 1.89	93.6
	10	2.80	0.0245	0.0302	− 1.93	91.7
	20	2.76	0.0242	0.0304	− 1.97	90.6
10	0	3.19	0.0228	0.0239	− 0.48	110.1
	2	3.00	0.0228	0.0238	− 0.45	108.8
	5	3.14	0.0244	0.0257	− 0.94	107.9
	10	3.07	0.0242	0.0256	− 0.92	107.1
	20	3.31	0.0242	0.0264	− 1.11	108.8

I. Susceptibility factor. (Table 1～3)

A. Natural rubber powder "Mealorub".

At first stage of mixing and heating of asphalt and rubber, the addition of the rubber causes remarkable decreases of the susceptibility factor. These decreases are proportional to the increase of rubber contents. The decrease in susceptibility factor are from 3.90 in rubber content 0% to 2.05 in rubber content 10%. In the blend which was heated for 2 hours, the sensitivity was increased, i.e., from 3.90 to 4.10 by 0% rubber addition, from 2.43 to 2.73 by 3% addition, from 2.27 to 3.03 by 5% rubber addition, from 2.04 to 3.00 by 7% rubber addition, 2.05 to 3.30 by 10% rubber addition; this tendency was the same as in the blend heated 2, 5, 10 hours, respectively. But in the blends heated 20 hours, the susceptibility factor is smaller than in the blend heated 10 hours. In the blends which were heated for the same period, the susceptibility factor decreased with the increase of the amount of the rubber. These tendencies show that the penetration is too high at high temperature, and does not always show the decreases of the susceptibility to temperature changes. This tendency is common on all kinds of rubber tested.

B. Reclaimed rubber powder "N".

The addition of a small amount of rubber "N" did not bring about any decreases of susceptibility factor, but the addition of 30% of rubber resulted in decrease of susceptibility. The heating time also did not cause changes of the susceptibility factor.

C. Reclaimed rubber powder "A".

The addition of 5% of rubber "A" brought a remarkable reduction of the susceptibility factor, i.e., the susceptibility factor decreased from 3.90 to 2.50 on 0 hour heating, and then by the addition of 10%, the sensitivity increased to 3.19. The sensitivity of the blends with rubber "A" were not affected by the heating time.

II. Penetration temperature susceptibility. (**P. T. S.**)

A. Natural rubber powder "Mealorub".

In the first stage of the heating and mixing, all blends had a higher penetration temperature susceptibility than asphalt itself; then by heating for 2 hours, the P. T. S. was decreased in all rubber asphalt blends. Also, the P. T. S. was decreased by increase of the rubber contents, and by the lengthening of the heating period.

B. Reclaimed rubber powder "N".

In the first stage of blending, the P. T. S. showed higher value than that of the asphalt itself, but the increase of heating time brought the decrease of penetration temperature susceptibility in all blends. These decreases were proportional to the increases of the rubber content.

C. Reclaimed rubber powder "A".

The addition of the rubber powder brought marked decreases in P. T. S.. They were remarkble in the blends heated 2 hours.

III. Penetration index.

Penetration index is calculated from the penetration temperature susceptibility. These results are the same as those obtained in the case of P. T. S. for all kinds of the blends.

IV. Float test index.

A. Natural rubber powder "Mealorub".

As in the case of asphalt itself, the increase of heating time brings marked increae of the float test index. Generally low sensitive asphalt has 90 or more float test index. In the blend heated 0 hour, the float test index was smaller than that of asphalt itself, but the increase of the heating time brought the increase of float test index, and the increase of rubber content brought increase of float test index within 5 hours heating. Further heating, reversely, brought about a decrease of float test index.

B. Reclaimed rubber powder "N".

In the blends with rubber powder "N", the addition of the rubber brought considerable increase: also, the increase of heating time brought increase of float test index.

C. Reclaimed rubber powder "A".

The addition of 5% of the rubber did not bring about an increase of float test index. The addition of 10% of rubber resulted in the remarkable improvement on the temperature sensitivity. The variation of the heating time does not show the increase of float test index.

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 phenomena show that the methods of calculation do not always show the actual temperature sensitivity.

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

Such changes in temperature sensitivity would make the pavement less brittle in cold weather and more stable in hot weather, but it also is apparent that the changes produced are not the same for each type of the rubber tested.

Chap. 3 Dynamic test by a Page impact testing machine

The impact resistance, that is the toughness of the rubber blended asphalt mortars, was 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. The mineral filler was a limestone dust passing No. 200 sieve.

To make the asphalt mortar, sea sand produced from Nishikioka, Hokkaido, was used. The characteristics of the sand are as follows:

specific gravity	2.762
percent of absorption	0.5 %
unit weight	1,752 kg/m^3

grading

sieve opening (mm)	pass percent
1.2	100
0.6	78
0.3	24
0.15	2
0	0

The mixture was composed of 12.5% asphalt, 5% mineral filler and 82.5% sand, while the rubber content in the asphalt was 0, 3, 5, 7% in the blend with natural rubber powder "Mealorub", and 5, 10% in the blend with reclaimed rubber powder, by weight, respectively.

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

The size of the specimen to be tested was determined according to the capacity of the testing machine after the preliminary test on the selection of suitable size had been made. Cylinders measuring 35 mm × 30 mm were found most suitable. The molding forms were cut from a steel pipe.

The asphalt-rubber blend was prepared by the same method as described in Chap. 2. Prior to mixing, the materials for each specimen were heated to about 100~110°C, during 15 to 20 minutes, and then poured into the steel form. The mixtures in the mould were allowed to cool to 40~50°C, then they were pressed under the load intensity of about 200 kg/cm². 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 respective temperatures of the specimens to be tested were secured in various ways. Temperatures of specimens 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 was obtained by means of a bath filled with dry-ice. All temperatures lower than 0°C were secured in a low-temperature room.

The Page impact tests here reported for temperatures 20°C and 10°C, were made in a room of 10°C to 20°C; and for 0°C was made in a low temperature room of 0°C to 5°C; those made in temperatures lower than −10°C, were made in the low-tempeaature room of −15°C to −20°C.

On the measurement of toughness, the height of the drop hammer of 1 kg, was increased by 1 cm., for each succeeding blow until ruptures of a specimen occurred. The height from which the hammer fell when rupture occurred was taken as a numerical value indicative of the toughness of the material under test. At low temperature, a failure of the specimen was clearly recognized if they broke into two or three pieces, but at comparatively high temperature, judgement of the occurrence was rather difficult.

Test results:

As to the results of the toughness tests, the following conclusions were reached; figures show the results graphically:

Figs. 16~43 show the relations between the toughness of all the kinds of blends and test temperature, full lines denote beaking of specimens and dotted lines cracks, Figs. 45 and 46 show the relation between the toughness and the heating time, and Fig. 44 shows the relations between the toughness and the amount of added rubber.

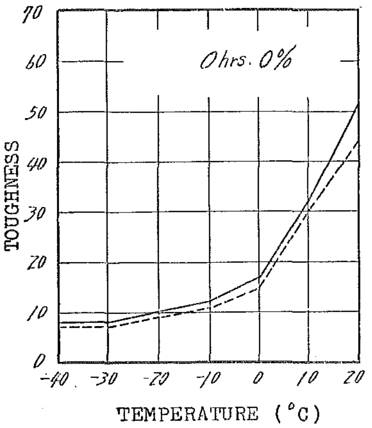


Fig. 16.

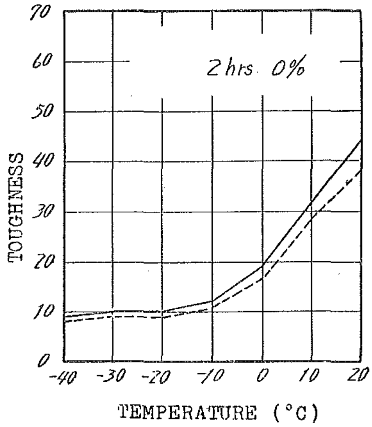


Fig. 17.

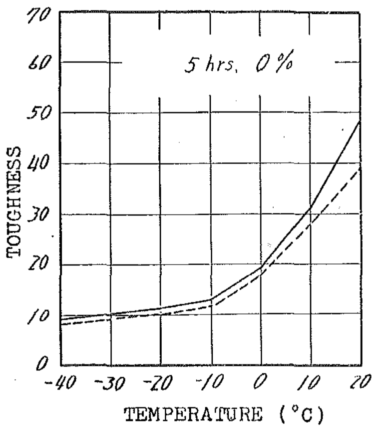


Fig. 18.

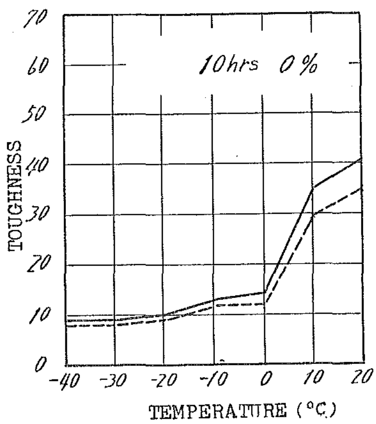


Fig. 19.

Figs. 16 to 19

Relation between toughness and temperature on original asphalt, heated 0, 2, and 10 hours.

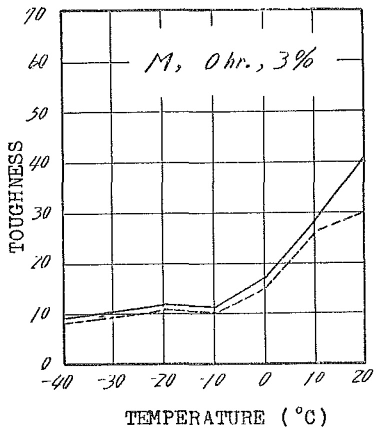


Fig. 20.

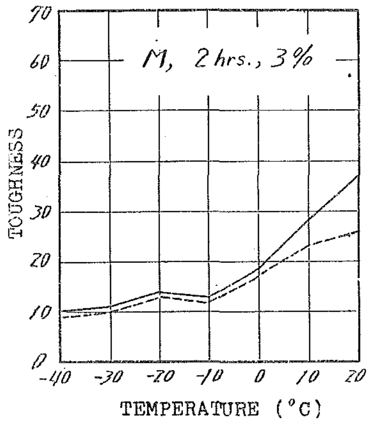


Fig. 21.

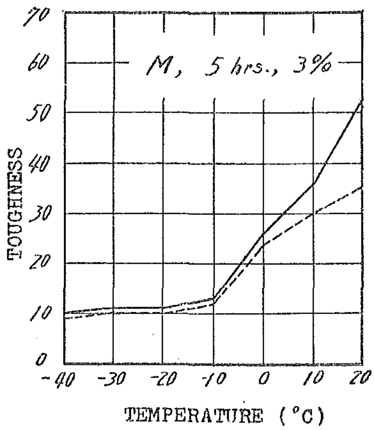


Fig. 22.

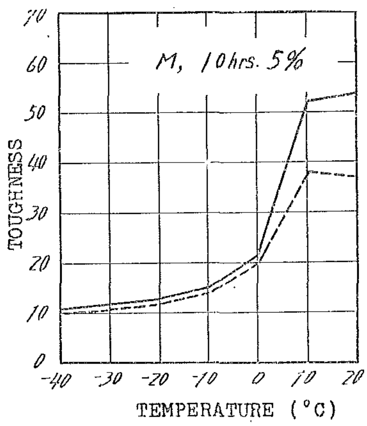


Fig. 23.

Figs. 20 to 23

Relation between toughness and temperature
on blend with 3% Mealorub.

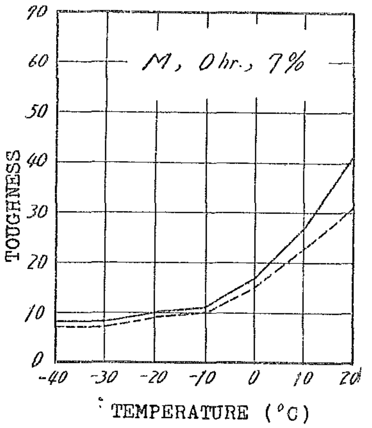


Fig. 24.

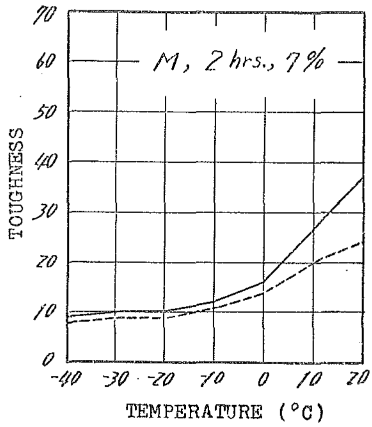


Fig. 25.

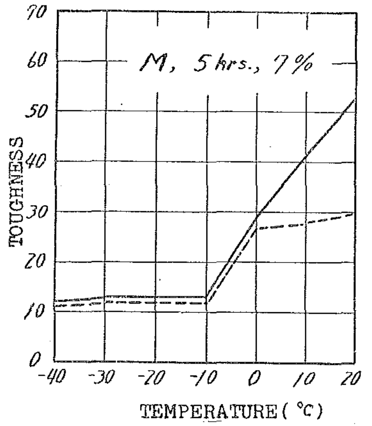


Fig. 26.

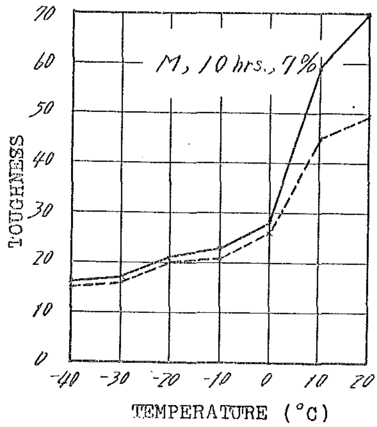
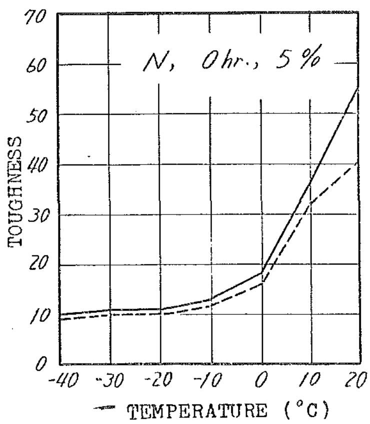


Fig. 27.

Figs. 24 to 27

Relation between toughness and temperature on blend with 7% Mealorub.



F.g. 28.

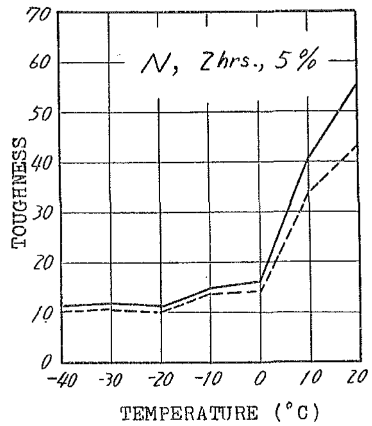


Fig. 29.

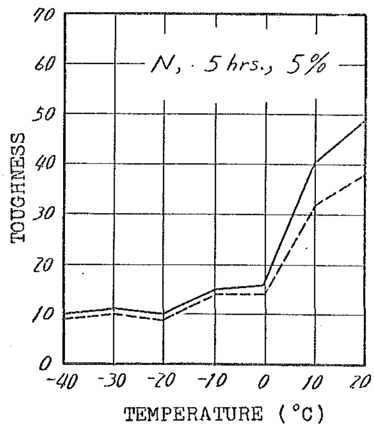


Fig. 30.

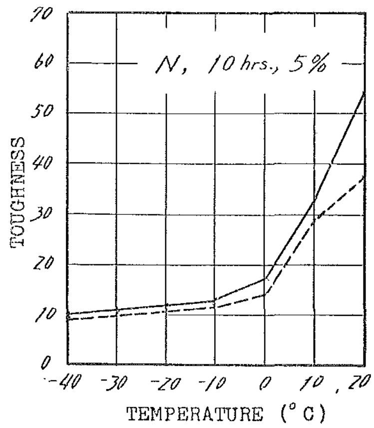


Fig. 31.

Figs. 28 to 31

Relation between toughness and temperature
on blend with 5% "N".

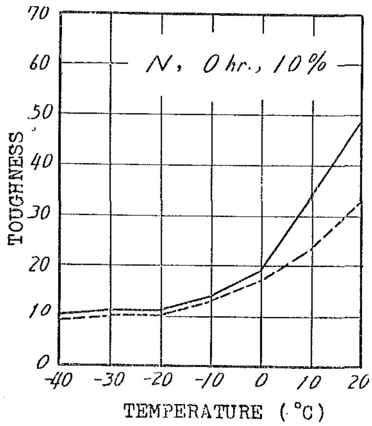


Fig. 32.

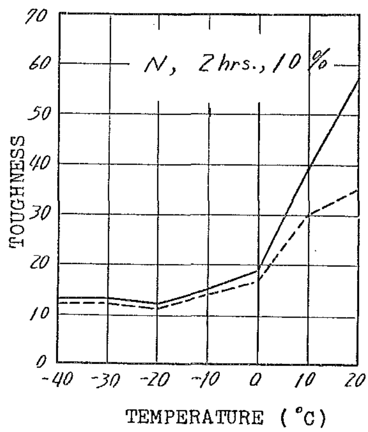


Fig. 33.

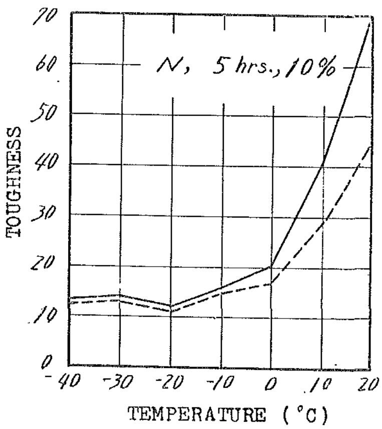


Fig. 34.

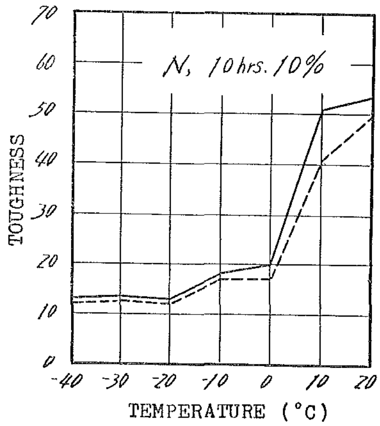


Fig. 35.

Figs. 32 to 35

Relation between toughness and temperature on blend with 10% "N".

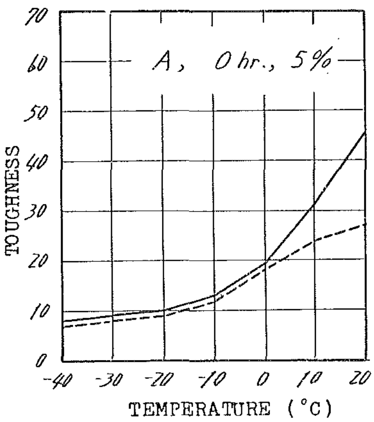


Fig. 36.

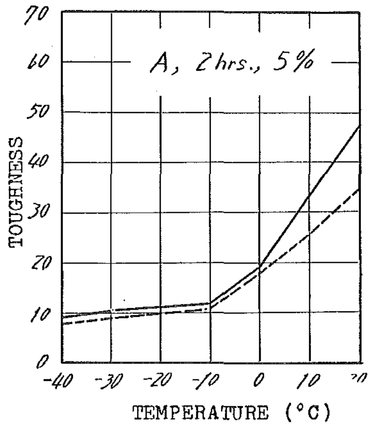


Fig. 37.

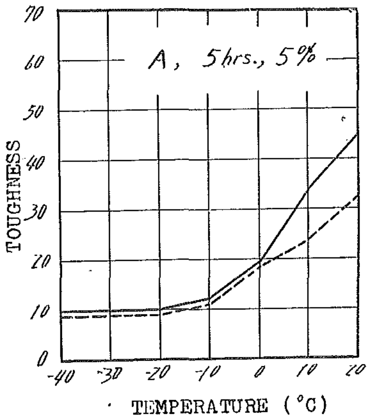


Fig. 38.

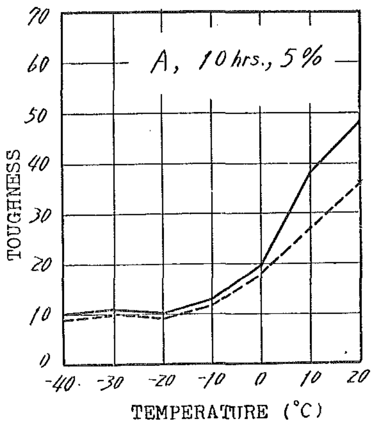


Fig. 39.

Figs. 36 to 39

Relation between toughness and temperature
on blend with 5% "A".

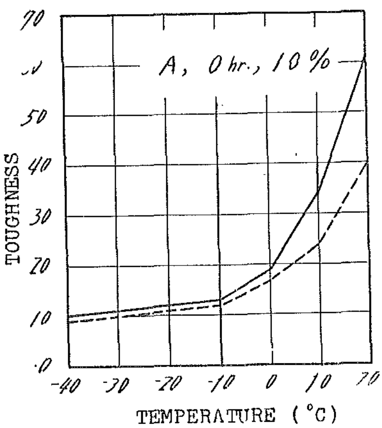


Fig. 40.

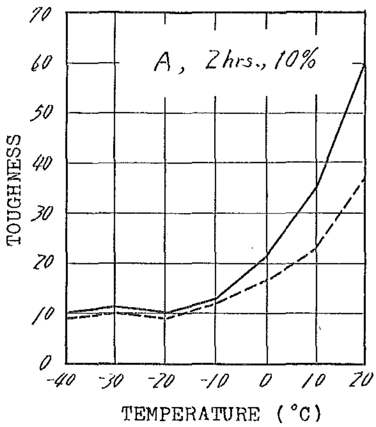


Fig. 41.

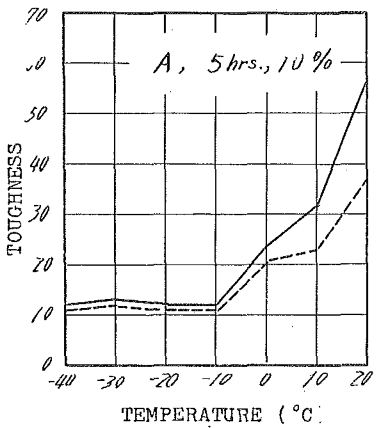


Fig. 42.

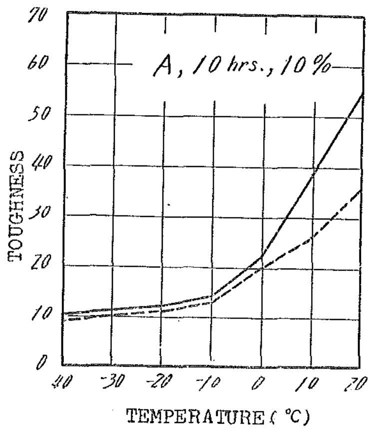


Fig. 43.

Figs. 40 to 43

Relation between toughness and temperature on blend with 10% "A".

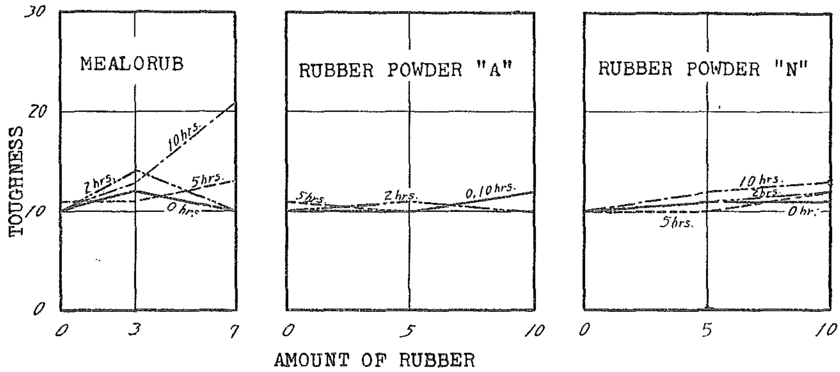


Fig. 44 Relation between the toughness and the amount of the rubber at $-20°C$.

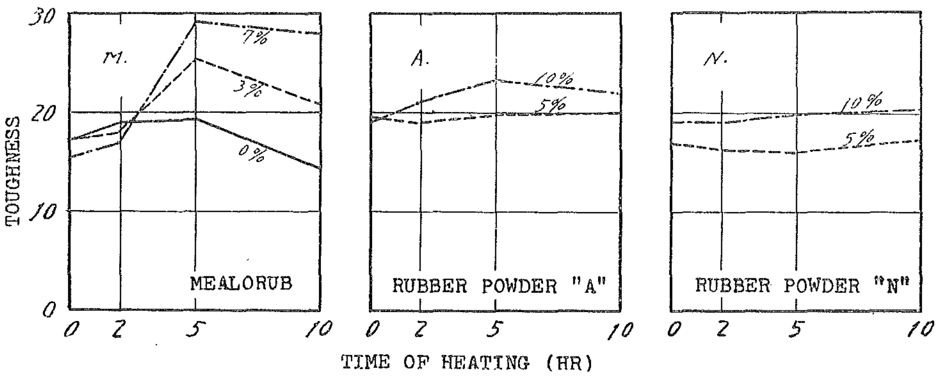


Fig. 45 Relation between toughness and time of heating at $0°C$.

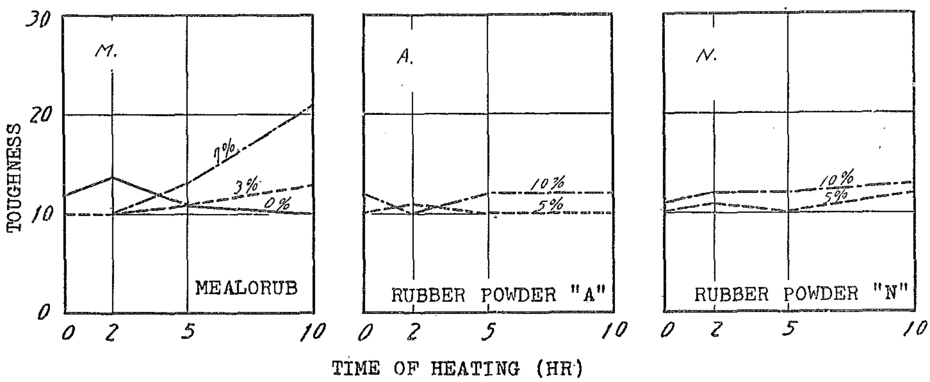


Fig. 46 Relation between toughness and time of heating at $-20°C$.

1) Relation between toughness and test temperature. (Figs. 16∼43)

The toughness measured by a Page impact testing machine was generally reduced in accordance with lowering of test temperature, as shown in the figures; the rate of reduction of brittleness showed a parabolic relation at higher than −20°C, and straight line relation at lower than −20°C. The general shapes of the relationship between temperature and toughness were the same in each of the blends as shown in the figures. But there were considerable differences on the absolute values of the toughness of the blends composed of the three kinds of rubber. Generally, the addition of the rubber caused considerable increase of the toughness value.

2) Relation between toughness and the amount of rubber. (Fig. 44)

a. Mealorub:

Generally, increase in the amount of rubber brings increase of the toughness excepting when the blend has been heated for a long time.

b. Reclaimed rubber "A", "N":

The increase of the amount of the rubber, generally, brings the increase of toughness, but these increases are not remarkable.

3) Relation between the toughness and the heating time. (Figs. 45, 46).

a. Original asphalt:

At the first stage of heating, the toughness at low temperature was increased within 2 hours heating, but prolongation of the heating time brought decrease of the toughness. In one case toughness was decreased from 51 to 40 by 10 hours heating at test temperature 20°C.

b. Mealorub:

At test temperature 0°C, on 5 hours heating, the toughness was increased for all blends; and the grade of increase was considerable in the blends containing comparatively larger amounts of rubber, but the toughness was decreased after 5 hours' heating. It is of interest that the toughness was on the increase during 10 hours' heating at −20°C test temperature. This fact shows that the improvement of shock resistance at low temperature is remarkable in the blends heated for a long time.

c. Reclaimed rubber powder "A", "N":

There were no remarkable differences caused by heating in the materials in which both "A" and "N" were mixed at all test temperatures.

Among the above three kinds of rubber, the improvement of shock resistance at low temperature is largest in case of the use of Mealorub. This is also clear at high temperatures.

Chap. 4 Summary and conclusions

Based upon the results of these tests on rubber blended asphalt and asphalt mixtures, the following conclusions were reached.

1. Penetration was affected by the addition of rubber; there are remarkable differences in penetration of the rubber blended specimens which were subjected to different heating periods, and made with the different kinds of rubber. In Mealorub heated for 3 to 4 hours, the penetration value was decreased proportionally to increase of the amount of the rubber, but with the increase of heating time, the penetration was increased to reach its maximum at 5 hours heating. In the blend heated 5 hours or more, the specimen with large amount of rubber combined, showed large penetration. After 5 hours heating, the penetration was decreased on all blends.

In cases of the samples with reclaimed rubber "N", heated 2 hours, the penetration increased remarkablly. Such sample does not show the maximum within 20 hours heating, but the increase in the penetration in case of the increase of heating time is remarkable in all blends.

In reclaimed rubber "A", the differences cause variation of the heating time and the amount of the rubber in all rubber contents; and these values are lower than corresponding ones of the original asphalt. (Figs. 1∼3)

2. In ductility, the blends with Mealorub showed increase with the increase of the amount of the rubber and heating period. In comparison with original asphalt, the ductility showed considerable increase at low temperature in the blends with Mealorub. In rubber powder "N", the increase of the amount of the rubber brings remarkable increase of ductility of the blends. (Figs. 4∼6)

3. In float test, the changes causing difference of the heating time are remarkable in the blend heated 2 hours. After 2 hours heating, the softening point was decreased in all blends, while the increase of the amount of the rubber, generally, caused increase in float value, but there are no effects in the blends with "A". (Figs. 7∼12)

4. Softening of the rubber blended asphalt showed an increase in all cases using rubber within 2 hours heating; the increase is re-

markable in the blends with "N" heated 5 hours, and blends with Mealorub heated 2 hours. But there are no differences in the material causing difference of the heating time in the blend with "A". In cases of rubber powder "N", the increase of the amount of the rubber brings remarkable increase in softening quality. (Figs. 13～15)

5. There were no considerable changes in specific gravity, flash point and burning point.

6. Identical results were not obtained by the 5 methods which were employed to find the temperature sensitivity of the rubber blended asphalt. By the use of some methods the asphalt showed decrease of sensitivity, and by other methods, it showed increase. Accordingly, it must be said that these 5 methods do not always show the true sensitivity to temperature change. Then it is necessary to establish a calculation method for obtaining temperature sensitivity.

But, generally, the sensitivity was improved because the flow property was decreased and the penetration was increased or slightly decreased. (Tables 1～3).

7. The shock resistance of the rubber blended asphalt mixtures was improved. This is remarkable in case of samples with Mealorub combined; there was considerable improvement in the blend with rubber powder "A". The increase of shock resistance at low temperature is remarkable on the blends heated for a long period. (Figs. 16～46)

Future development.

The authors are now investigating the effect on the asphalt mixtures in cases of the addition of rubber latex.

The results and comparison with various kinds of rubber described in this paper will be discussed in the near future.

Acknowledgements

These investigations were carried out in the Highway Engineering Laboratory, Hokkaido University, Sapporo, Hokkaido, Japan.

The authors wish to express their appreciation to Dr. Ir. L. W. Nijiboer, Royal Dutch Shell Laboratory; The Texas Engineering Experimental Station; Prof. Fred J. Benson of the Agricultural College of Texas, and to INITORO for kind advice in the course of the performance of this investigation. They also wish to acknowledge their indebtedness to R. H. Lewis, J. Y. Welborn, H. M. Rex, and R. A. Peck for helpful suggestions in their research reports.

Finally appreciation is expressed to T. Kaku, T. Kamiyama, A. Nakajima, Y. Nakata, K. Hayashi and T. Sasaki for helpful and earnest assistance during these investigations.

References

1) Chūzo Itakura, Teruo Sugawara: "Dynamic test on the stability of bituminous mixtures for pavement at low temperatures". Memoirs of Faculty of Engineering, Hokkaido University, Vol. 9, No. 4 (No. 42), Nov. 1954.

2) Chūzo Itakura, Teruo Sugawara: "Dynamic tests on the stability of bituminous mixtures for pavement at low temperatures. (II) Experimental Researches on rubber blended asphalt and asphalt mixtures". Memoirs of Faculty of Engineering, Hokkaido University, Vol. 10, No. 1 (No. 43) Sept. 1955.

3) Richard H. Lewis, J. York Welborn: "The effect of various rubbers on the properties of petroleum asphalts". Public Roads, Oct. 1954.

4) "Kautschuk in Asphaltstrassen". Rubber-Stiching, (Delft Holland).

5) Harry M. Rex, Robert A. Peck: "A laboratory study of rubber-asphalt paving mixtures". Public Roads, Oct. 1954.

6) Richard H. Lewis, J. York Welborn: "The physical and chemical properties of petroleum asphalt 50-60 and 85-100 penetration grade". Public Roads, Vol. 21, No. 1, 1940.

7) "Rubber in Roads". Roads and Road Construction, Vol. 29, No. 346, Oct. 1951.

8) "Further rubberised asphalt trials". Roads and Road Construction, Vol. 29, No. 347, Nov. 1951.

9) Cut asphalt content of rubber paving". Engineering News Record. Vol. 148, Jan. 3, 1952.

10) "Rubber gets airfield trial". Engineering News Record. Vol. 148, No. 13, Mar. 1952.