Some Effects of Rubber Additives on Asphalt Mixes

R. J. SALTER AND J. MAT

The effects of three types of rubber on the behavior of asphaltic concrete (AC) mixes have been investigated by first determining the changes that rubber additives have on the properties of the bitumen binder. Changes in penetration, softening point, and penetration temperature susceptibility with rubber-bitumen blends are reported. Force ductility tests were also carried out to investigate the changes in the properties of rubber-modified binders at low temperatures. The Marshall method was used to determine changes in optimum binder content consequent to incorporation of rubber into the mix. Flexural testing of beam specimens was carried out using cyclic loading to investigate the changes in the fatigue properties of AC mixes caused by the addition of rubber. Within the limitations of the experimental work, the incorporation of the rubber into binders generally improved the properties of binders and mixes as determined by laboratory testing.

Increasing traffic flows and associated increases in axle loading experienced on highway systems in the developed and developing world together with demands that maximum life and minimum maintenance costs be achieved have led highway engineers to investigate how the properties of asphaltic highway pavement materials might be improved by the use of additives.

The effects of rubber were investigated as an additive to asphaltic mixes, a topic of particular interest to highway engineers in Malaysia. The following three types of natural rubber were used in the experimental work:

1. Pulvatex, manufactured in Great Britain by Rubber Latex, is an unvulcanized rubber powder manufactured from concentrated natural latex, of composition 60 percent natural rubber powder and 40 percent separator.
2. Crusoe Standard, manufactured in Great Britain by Harrison and Crossfield, is an unvulcanized spray-dried rubber powder containing approximately 6 percent silica filler and 1 percent calcium stearate as a partitioning agent.
3. LCS Revertex, manufactured in Great Britain by Revertex, is an unvulcanized latex concentrated by evaporation to 68 percent solids and stabilized with potassium hydroxide and soap.

The experimental work investigated the following effects of addition of natural rubber powders:

1. Effects on physical properties of the bitumen,
2. Effects on design of asphaltic concrete (AC) mixes (investigated using the Marshall method), and
3. Effects on fatigue life of AC beam specimens when tested under constant strain.

R. J. Salter, University of Bradford, Emm Lane, Bradford, England. J. Mat, University of Technology, Jalan, Gurney, Kuala Lumpur, Malaysia 54100.

BINDER PROPERTIES AND RUBBER BITUMEN BLENDS

Materials used in the experimental investigation were selected so as to be similar to those used in Malaysian practice and to comply with current Public Works Department specifications. The bitumen, supplied in Great Britain by Croda Hydrocarbons, had a penetration of 98 at 25°C and a ring- and ball-softening point of 47°C. Blends of natural rubber-bitumen were prepared using concentrations of 3, 5, and 7 percent by mass of rubber to bitumen. The blends were prepared in the laboratory with the blend at a temperature of approximately 135°C; stirring of the rubber into the bitumen took place for 30 min.

All prepared blends were given separate designations for identification in subsequent testing. Details of the mixes used are presented in Table 1.

Penetration tests were carried out on the rubber-bitumen blends and on the control of unmodified bitumen. The results are presented in Table 2 and indicate decreasing penetration with increasing rubber content, the greatest reduction in penetration being obtained from Revertex. Table 2 also presents the softening points of the blends, which increased with increasing rubber content for all blends, the greatest increase in softening point occurring with the use of Revertex as an additive.

For the blends tested, the maximum reduction in penetration, which occurred with 7 percent blends, was 29.5 percent for blends containing Pulvatex, 22 percent for blends containing Crusoe Standard, and 35 percent for blends containing Revertex. Comparison of softening point values indicated an increase of 28 percent in softening point obtained with the liquid latex Revertex with 7 percent additive.

Penetration indices for the blends were also calculated because this index was considered a good indicator of the temperature susceptibility of the blend. The index proposed by Pfeiffer has been commonly used in rubber-bitumen investigations. The calculation was carried out in two stages, the first stage determining the penetration temperature susceptibility (PTS) from the relationship

$$\mathrm{PTS} = \frac{\log 800 - \log p}{t - 77}$$

where p is the penetration (25°C, 100 g, 5 sec) and t is the softening point (°F).

TABLE 1 RUBBER-BITUMEN BLEND DESIGNATIONS

Binder Designation	Additive	Additive Content (percent)
P100	none	0
PVT3	Pulvatex	3
CST3	Crusoe	3
LCR3	Revertex	3
PVT5	Pulvatex	5
CST5	Crusoe	5
LCR5	Revertex	5
PVT7	Pulvatex	7
CST7	Crusoe	7
LCR7	Revertex	7

TABLE 2 PENETRATION AND SOFTENING POINT VALUES FOR RUBBER-BITUMEN BLENDS

Binder Designation	Penetration	Softening Point (°C)
P100	98.0	47.0
PVT3	81.5	51.4
CST3	84.0	50.2
LCR3	78.2	51.8
PVT5	73.1	53.6
CST5	79.1	52.4
LCR5	67.4	54.6
PVT7	69.1	57.1
CST7	76.0	55.0
LCR7	63.6	60.0

TABLE 3 PENETRATION TEMPERATURE SUSCEPTIBILITY AND PENETRATION INDEXES FOR RUBBER-BITUMEN BLENDS

Binder Designation	PTS	PI
P100	0.0230	−0.236
PVT3	0.0209	0.409
CST3	0.0216	0.183
LCR3	0.0210	0.389
PVT5	0.0202	0.650
CST5	0.0204	0.587
LCR5	0.0202	0.658
PVT7	0.0184	1.281
CST7	0.0190	1.084
LCR7	0.0175	1.669

The second stage of the calculation determined the penetration index PI from the relationship

$$PI = \frac{30}{1 + 90PTS} - 10$$

Calculated values are presented in Table 3.

The indices presented in Table 3 show a reduction in temperature susceptibility over all the blends used when compared with the control binder. Because the penetration susceptibility index is the slope of the log penetration versus temperature curve for the respective penetration p and temperature t, its values indicate that the slope becomes less steep as the amount of rubber increases. This effect is similar to that described by Bokma (*1*) for the influence of rubber on penetration at varying temperature. In these experiments, the slope of the penetration-temperature curve decreased as the amount of rubber in the mix increased. These relationships demonstrated that rubber-bitumen blends are harder at higher temperatures and softer at lower temperatures than unmodified binders. The decreased temperature susceptibility, decreased penetration, and increased softening point are the major benefits of the use of rubber-bitumen blends. Al-Abdullah and Mesdary (*2*) found that the addition of natural rubber to 60/70 Kuwaiti bitumen results in a binder equivalent to heavy-duty bitumen, as recommended by the Transport and Road Research Laboratory for carrying heavy commercial vehicles in Great Britain. Heavy-duty bitumen has a penetration of 40 ± 10 and a softening point of 58°C to 68°C.

FORCE DUCTILITY TESTS

In addition to penetration and softening point tests, force ductility testing was carried out on the rubber-binder blends. The test measured tensile load-deformation characteristics of binders. The test apparatus consisted of apparatus for the ductility test (ASTM D113) using briquet specimens of the binder that were pulled apart by a tensile force while immersed in water at 4°C. The apparatus was modified by adding a load cell mounted in series between the drive mechanism and the sample. The force generated in the sample was measured using a data logger and microcomputer.

Force ductility results were reported as load required to cause elongation of the briquet sample. During the first 30 mm of elongation, the load was measured at every 1 mm of elongation and thereafter at every 10 mm of elongation until the specimen ruptured. A typical plot of the results obtained is shown in Figure 1, where the behavior of the specimen under load can be clearly seen. As the sample is pulled apart, the force increases until it reaches a peak; then the force decreases as the elongation of the specimen increases and finally becomes zero when the specimen ruptures. Figure 1 shows the force versus elongation relationship obtained for blends containing 7 percent additive.

Results of the force ductility tests, including the maximum tensile force, elongation of the specimen at maximum force, and elongation at rupture, are presented in Table 4.

The results indicate that rubber-modified binders exhibit higher maximum tensile load than the control binder except for blends containing 5 and 7 percent Crusoe Standard additive. The blend containing 7 percent liquid rubber (Revertex) demonstrated a 63.5 percent increase in strength.

MARSHALL TESTING PROCEDURE

An investigation into the effect of rubber blends on AC mix design was carried out using the Marshall mix design procedure as used by the Malaysian Public Works Department. This method is the only mechanical mix design test in current Malaysian practice.

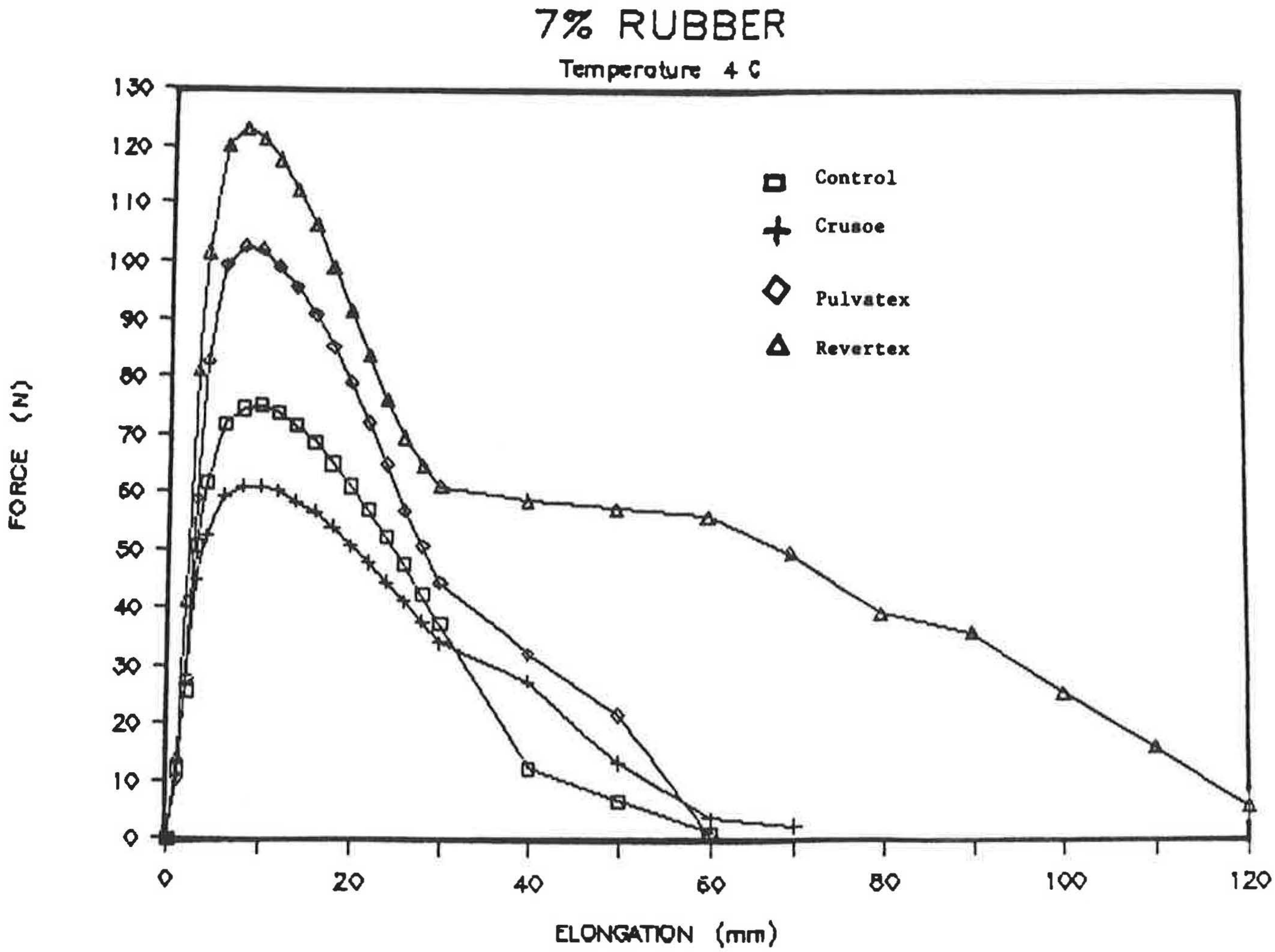

FIGURE 1 Force ductility test graphical output.

TABLE 4 RESULTS OF THE FORCE DUCTILITY TESTS

Binder Designation	Maximum Tensile Force (N)	Elongation at Maximum Force (mm)	Elongation at Rupture (mm)
P100	76.735	9	60
PVT3	79.330	10	70
CST3	83.795	9	60
LCR3	82.944	9	100
PVT5	96.475	8	70
CST5	75.993	8	70
LCR5	93.231	8	120
PVT7	102.776	8	60
CST7	61.536	9	70
LCR7	125.482	9	120

Materials for the AC mixes were typical of those used in Malaysia; limestone was used for both fine and coarse aggregate, and rubber-bitumen blends and control binder were used as previously described. Nominal size of the aggregate was 25 mm; the grading was in accordance with the Malaysian Public Works Department grading for binder courses.

Testing of the rubber-bitumen and control bitumen mixes was carried out in accordance with the Marshall procedure. The following parameters were related to binder content: unit weight, stability, air voids, voids in the mineral aggregate, and flow. Best-fit curves were obtained. A typical example for mixtures containing a 7 percent blend of Pulvatex and bitumen is shown in Figure 2.

For AC, mix design requirements of the Roads Division of the Malaysian Public Works Department specify values of stability, flow, voids in the total mix, voids filled with bitumen, and residual stability. Table 5 presents specified values for a binder course.

The binder contents corresponding to maximum stability, maximum unit weight, and midpoint (5 percent) of allowable air voids were determined. Optimum binder content was the average of these binder contents read from the smoothed curves of which Figure 2 is an example. Tables 6 and 7 present a summary of the mix design results for the rubber-bitumen blends and the control binder.

The Malaysian method of determining optimum binder content, previously described, differs from the method used in Great Britain (*4*) for hot-rolled asphalt wearing course. In the

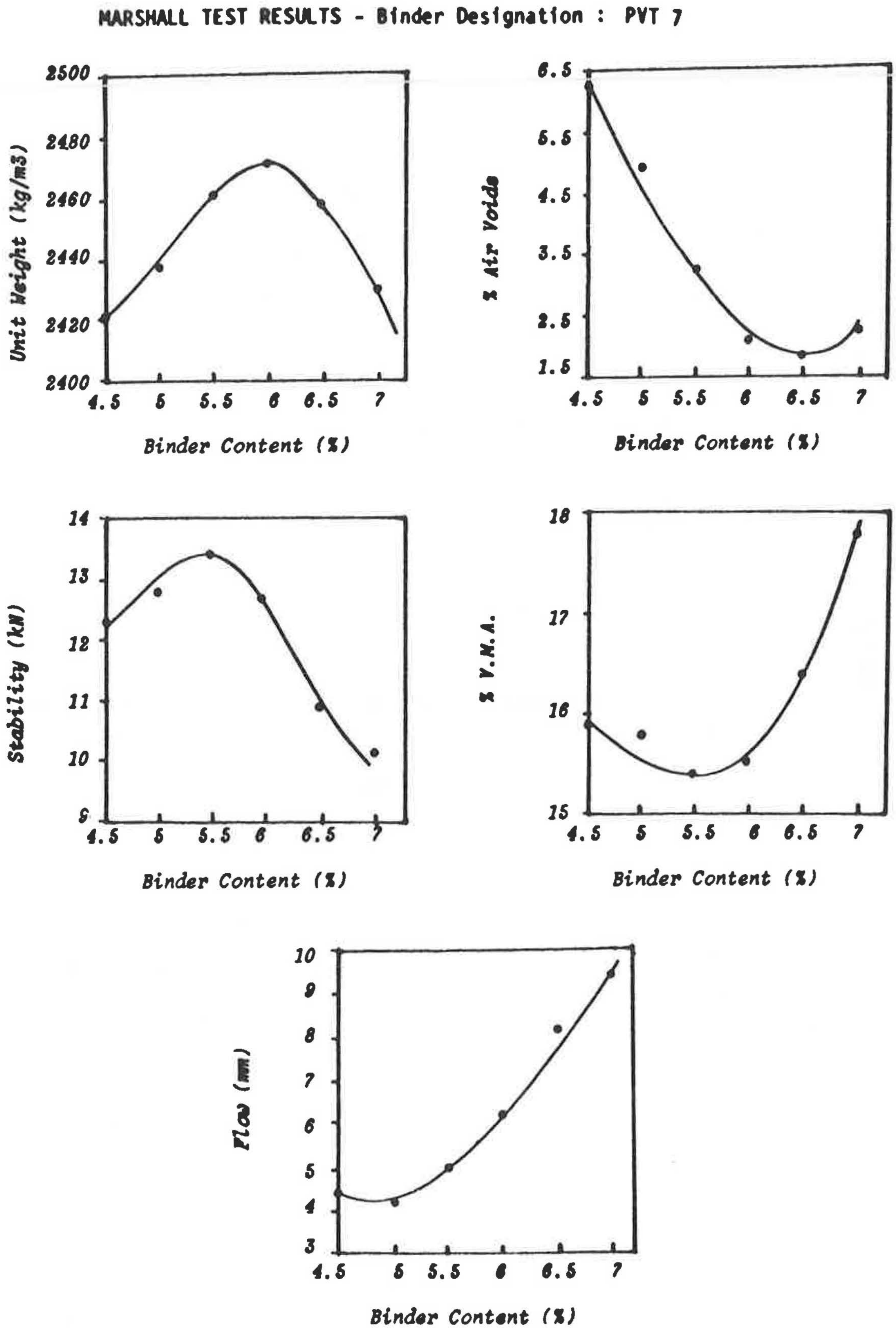

FIGURE 2 Determination of optimum binder content.

TABLE 5 REQUIREMENTS OF THE MALAYSIAN PUBLIC WORKS DEPARTMENT FOR AC BINDER COURSES

Stability (kg)	Not less than 500
Flow (1/100 cm)	20–40
Voids in total mix (percent)	3–7
Voids filled with bitumen (percent)	65–75
Residual stability (immersed percent)	Not less than 75

TABLE 6 DETERMINATION OF OPTIMUM BINDER CONTENT BY THE MALAYSIAN METHOD

Binder Designation	Binder Content at Maximum Unit Weight	Binder Content at Maximum Stability	Binder Content at 5 Percent Air Voids	Optimum Binder Content (percent)
P100	5.5	5.6	5.4	5.5
PVT3	5.7	5.8	5.2	5.6
PVT5	5.9	6.0	5.1	5.7
PVT7	6.0	5.5	5.0	5.5
CST3	5.7	6.0	5.5	5.7
CST5	6.0	5.8	6.0	5.9
CST7	6.2	6.0	6.1	6.1
LCR3	5.8	6.0	5.3	5.7
LCR5	6.0	6.2	5.1	5.8
LCR7	6.1	6.5	5.0	5.9

British method, evaluation of the design binder content is based on the average of the binder contents at maximum stability, mix density, compacted aggregate density, and flow, together with the addition of a factor depending on the coarse aggregate content of the mix. The difference between the two methods for determining optimum binder contents is obtained by comparing Tables 6 and 8. Except for the control mix and those containing Crusoe Standard, the British method yields higher optimum binder contents.

The basic difference between the methods is that the Malaysian approach is suited to the design of an AC mix in which voids are of considerable importance. Too high a binder content and a low voids content will lead to excess binder's reaching the surface of the pavement under traffic action in Malaysian climatic conditions. On the other hand, excessive air voids will lead to low durability. Sufficient binder should be used to produce air voids between 3 and 5 percent. The behavior of AC is sensitive to this figure; different target values should be used for different climatic and traffic conditions.

Within the limitations of the tests performed, the addition of rubber to the binder did affect the optimum binder content. For Pulvatex, the increase was inconsistent and relatively small. For 7 percent rubber-bitumen blends, no increase was observed, while at 3 and 5 percent a small increase was noted using the Malaysian method. Using the British method, a small increase was noted at all rubber concentrations. For Crusoe Standard and LCS Revertex, the optimum binder was increased for all rubber concentrations as determined by both the Malaysian and British methods.

Addition of rubber significantly affected the unit weight of the compacted mixes. For mixes containing Pulvatex and LCS Revertex, increasing the rubber content generally caused an increase in unit weight. For the samples containing Crusoe Standard, the unit weight decreased with increasing rubber

TABLE 7 MARSHALL QUOTIENT VALUES ON THE BASIS OF THE MALAYSIAN METHOD

Binder Designation	Stability at Optimum Binder (kN)	Flow at Optimum Binder (mm)	Marshall Quotient (kN/mm)
P100	11.0	3.6	3.06
PVT3	11.6	3.8	3.05
PVT5	12.5	4.7	2.66
PVT7	13.4	5.0	2.68
CST3	11.1	4.3	2.58
CST5	11.3	4.6	2.46
CST7	9.8	5.0	1.96
LCR3	11.8	4.3	2.74
LCR5	12.7	5.2	2.44
LCR7	12.8	6.1	2.10

TABLE 8 DETERMINATION OF OPTIMUM BINDER CONTENT BY USING THE BS 598 METHOD

Binder Designation	Binder Content at Maximum Unit Weight	Binder Content at Maximum Stability	Binder Content at Maximum Compacted Aggregate Density	Optimum Binder Content (percent)
P100	5.5	5.6	4.9	5.3
PVT3	5.7	5.8	5.3	5.6
PVT5	5.9	6.0	5.6	5.8
PVT7	6.0	5.5	5.7	5.7
CST3	5.7	6.0	5.4	5.7
CST5	6.0	5.8	5.7	5.8
CST7	6.2	6.0	5.9	6.0
LCR3	5.8	6.0	5.5	5.8
LCR5	6.0	6.2	5.9	6.0
LCR7	6.1	6.5	6.0	6.2

content, an effect considered to be caused by the coarser grading of the rubber particles, which affected the compatibility of the specimens.

Rubber content also affected the Marshall stability. For Pulvatex and LCS Revertex, stability increased as rubber concentration increased. For Crusoe Standard, increase in stability was not observed; the specimens containing a 7 percent blend had decreased stability, an effect associated with the decreased unit weight of these specimens.

Addition of Pulvatex and LCS Revertex caused air voids to decrease as the rubber content increased, while for specimens containing Crusoe Standard blends air void contents increased with increasing rubber contents.

Voids in the mineral aggregate (VMA) has been the most important mix design parameter affecting the durability of an AC mix (*5*). Except for Crusoe Standard, the addition of rubber reduced the VMA values compared to the control mix. In Malaysian practice, to satisfy the requirement for voids filled with bitumen indicated in Table 5 the minimum VMA value is about 14 percent. All the mixes investigated had a value that exceeded this minimum.

Increasing rubber content increased flow values. All the specimens containing rubber, except PVT3, had flow values that exceeded the maximum specified for Malaysian conditions. As the unmodified control specimens had flow values

approaching the maximum, a revised grading may have reduced the extent of the excess flow values.

Values of the Marshall quotient indicate the effect of addition of rubber to the mix. The increased values of flow cause a decrease in Marshall quotient despite increased values of stability.

FLEXURAL TESTING

Following the Marshall test procedure, a series of beam flexure tests were carried out on AC laboratory-prepared specimens to determine the effects of natural rubber powders and latex on fatigue life and dynamic modulus.

TABLE 9 EFFECT OF RUBBER-BITUMEN BLENDS ON FATIGUE LIFE OF AC BEAM SPECIMENS

	Mean Number of Cycles to		Percentage Increase in	
Sample	Fatigue Life	Severe Cracking	Fatigue Life	Severe Cracking
P100	23,568	27,500		
PVT3	28,825	35,625	22.3	29.6
PVT5	40,321	49,997	71.1	81.8
PVT7	44,359	50,010	88.2	81.9
CST3	29,725	36,876	26.1	34.1
CST5	36,251	43,672	53.8	58.8
CST7	35,285	44,997	49.7	63.6
LCR3	33,277	41,250	41.2	50.0
LCR5	37,753	50,718	60.2	84.4
LCR7	41,516	50,013	76.2	81.9

Constant-strain testing was adopted because it simulated strain conditions for pavements with relatively thin bituminous layers over granular bases. Sinusoidal loading was used with a frequency of 2 Hz; test temperature was 20°C ± 1°C. Binder and aggregate type and grading were as for the previously described Marshall testing program. Binder content was the optimum determined by the Malaysian method.

Specimens were prepared in the laboratory with a procedure similar to that used by the California kneading compactor. This method of specimen compaction simulated actual rolling conditions on the highway. Originally compacted to a size of 100 × 100 × 375 mm, specimens were cut to produce finished beam specimens measuring 37.5 × 37.5 × 375 mm.

Because the main objective of the testing program was to study the effect of natural rubber powders and latex on the fatigue life of the AC specimens under repetitive constant strain conditions, the criterion of failure was defined as the number of strain repetitions corresponding to a reduction in the load applied to the beam to half its value after the first 200 repetitions of load.

Four beams of each mix type were tested. The application of sinusoidal load was continued until cracking was observed in the beam specimens. Results of the test are presented in Table 9, in which considerable increases both in fatigue life and in cycles to cracking can be seen.

During testing, the variation in applied load with increasing cycles of applied load was noted. Relationships between load and repetitions are shown graphically in Figures 3–5, in which the behavior of specimens containing the three types of rubber additive and the control mix is compared.

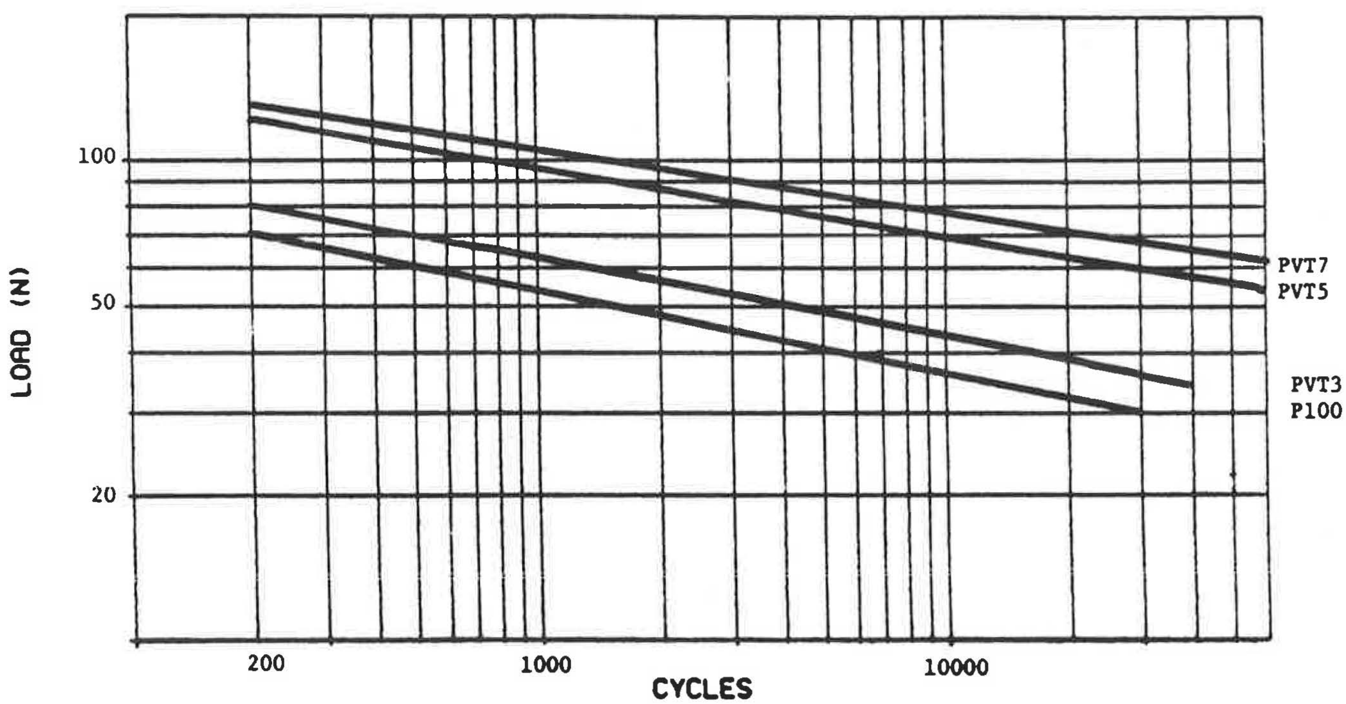

FIGURE 3 Relationships between applied load and cyclic loading for PVT mixes.

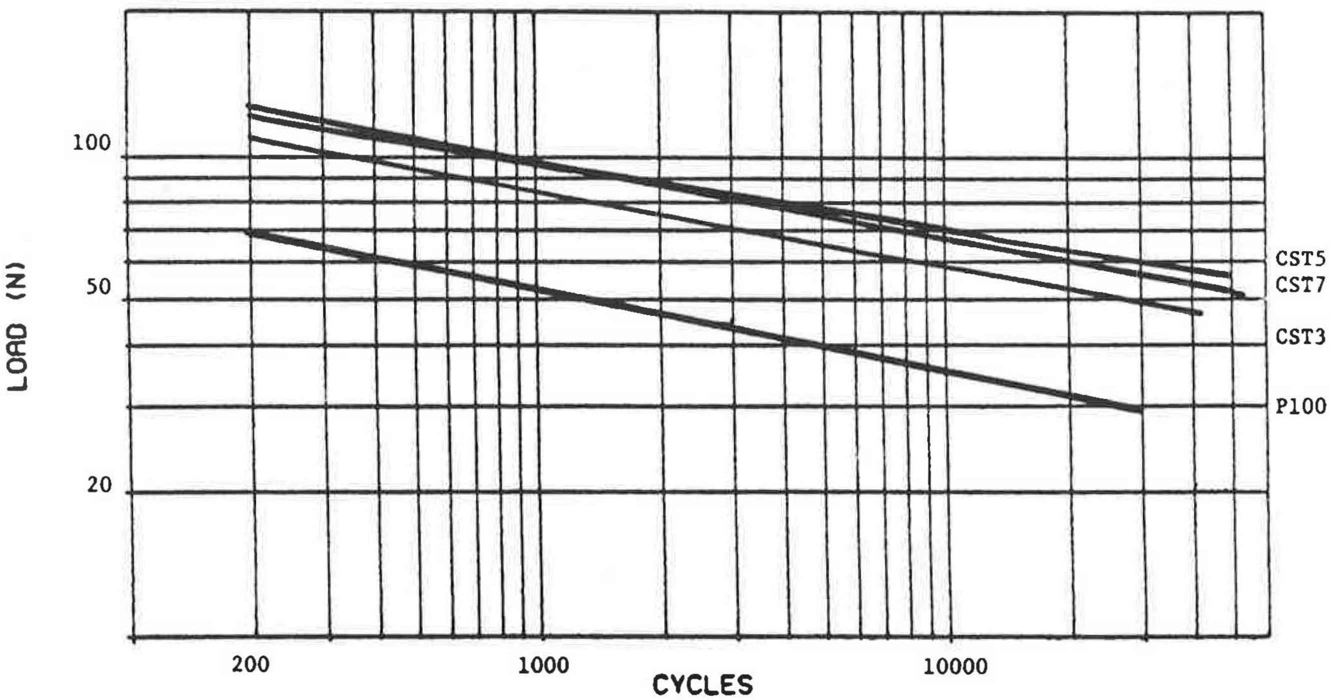

FIGURE 4 Relationships between applied load and cyclic loading for CST mixes.

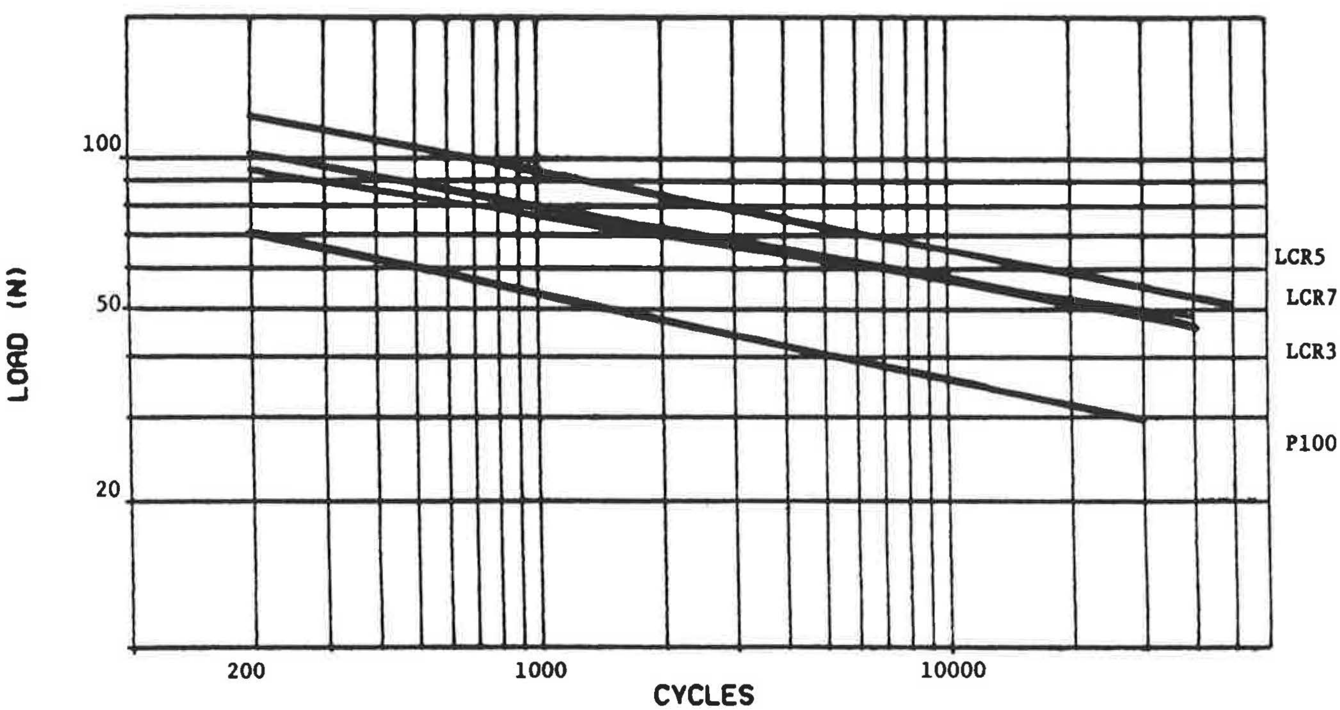

FIGURE 5 Relationships between applied load and cyclic loading for LCR mixes.

CONCLUSIONS

During the testing, the addition of all three types of rubber additive caused a decrease in penetration and an increase in softening point compared to the unmodified binder. Little variation in these properties was observed between the three types of rubber additive. An investigation into the temperature susceptibility of rubber-bitumen blends demonstrated decreased susceptibility compared to the unmodified binder.

Force ductility tests on modified and unmodified specimens at 4°C indicated that rubber-modified binders, with the exception of blends containing Crusoe Standard additive, exhibited higher maximum tensile loads during testing.

The Marshall testing program revealed a small increase in optimum binder content for most of the rubber-bitumen blends tested. The addition of rubber increased Marshall stability values for Pulvatex and LCS Revertex blends, but not for blends containing Crusoe Standard additive. Flow values were increased by the addition of rubber, a factor that should be considered in the overall design of mixes.

In a series of fatigue tests using beam bending to constant strain, the increase in fatigue resistance for rubber-bitumen blends was clearly indicated. When beam failure was defined as the reduction in applied load to half its initial value, improvements of up to 88 percent were noted in fatigue life. Similar improvements were found when the point of failure of specimens was defined as the onset of crack formation in the specimens.

REFERENCES

1. F. T. Bokma. The Use of Rubber in Bituminous Road Construction. *Communication 96, Rubber-Stichting*, Delft, Holland, 1949.
2. A. Al-Abdullah and M. S. Mesdary. The Impact of Research on Road Development in Kuwait. *Proc., 3rd IRF Middle East Regional Meeting*, Vol. 4, Riyadh, Saudi Arabia, 1988, pp. 263–280.
3. *Design and Construction of Asphalt Pavements*. Roads Division, Public Works Department, Malaysia, 1984.
4. *Sampling and Examinations of Bituminous Mixtures for Roads and Other Paved Areas*. British Standard 598: Part 3. British Standards Institution, London, 1985.
5. P. S. Kandhal and W. S. Koehler. The Marshall Mix Design Method, Current Practices. *Proc., Association of Asphalt Paving Technologists*, Vol. 54, St. Paul, Minn., 1985, pp. 284–303.

Publication of this paper sponsored by Committee on Characteristics of Nonbituminous Components of Bituminous Paving Mixtures.