Changes in Composition of Highway Asphalts, 85-100 Penetration Grade. Proc., AAPT, Vol. 31, 1962.

7. N.F. Coetzee and C.L. Monismith. An Analytical Study of the Applicability of a Rubber-Asphalt Membrane to Minimize Reflection Cracking in Asphalt Concrete Overlay Pavements. Department of Civil Engineering, Univ. of California, Berkeley, Geotechnical Engineering Rept., June 1978.
8. B.A. Vallerga and J.R. Bagley. Design of Asphalt-Rubber Single Surface Treatments with Multilayered Aggregate Structure. ASTM, Philadelphia, Special Tech. Publ. 724, 1979, pp. 22-38.
9. B.A. Vallerga, and others. Applicability of Asphalt-Rubber Membranes in Reducing Reflection Cracking. Proc., AAPT, Vol. 49, 1980, pp. 330-353.
10. Specification for ARM-R-SHIELD. Arizona Refining Co., Phoenix, Spec. M-101, 1976.
11. Construction Specification for ARM-R-SHIELD Surface Treatment. Arizona Refining Co., Phoenix, Spec. C-201, 1976.
12. Construction Specification for ARM-R-SHIELD Stress Absorbing Membrane Interlayer. Arizona Refining Co., Phoenix, Spec. C-202, 1976.

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Modification of Paving Asphalts by Digestion with Scrap Rubber

JOHN W.H. OLIVER

The service performance of sprayed surface treatments laid where traffic-induced stress is severe or where the existing pavement is cracked can be significantly improved if comminuted scrap rubber is digested in the asphaltic cement before spraying. Work performed to identify the factors that are of importance in optimizing asphalt performance is reported. Measurement of the deformation response of the rubber digestions to sinusoidal loading indicated that the modified binder had improved response under the loading produced by traffic at high pavement temperatures and that produced by thermal contraction at low pavement temperatures. A simple and rapid test procedure was developed to measure the response under loading conditions similar to these. The procedure is to subject a prism of the binder at 60°C to a shear strain of 1.0-in creep and then determine the elastic recovery when the stress is removed. The most important factor affecting elastic recovery was found to be the morphology of the rubber particles as determined by the comminution process used in their manufacture. A simple bulk-density test was used to characterize this morphology. Digestions of natural (truck-tire) rubber are generally superior to those that incorporate synthetic (car-tire) rubber but are more affected by changes in the time or temperature of digestion. Where a cryogenic comminution process had been used, only digestions of natural-rubber particles produced a significant improvement in asphalt properties. Elastic recovery of strain is linearly related to rubber concentration.

Rubber modifiers have been used in bituminous materials for many years. They have usually been specially prepared natural and synthetic rubbers, and their concentration has been limited to less than 5 percent by mass of the asphaltic cement because greater concentrations have caused problems in handling (pumping and spraying) and because of their high cost. At these concentrations, the improvement in binder performance obtained in pavement service has been marginal unless a satisfactory polymer network has been formed in the asphalt.

A major improvement in this situation occurred as a result of the work of McDonald (1) and Morris and McDonald (2), who introduced the use of digestions of scrap rubber in asphalt that contained up to 25 percent by mass of comminuted tire-tread rubber. A sprayed layer of this material has been widely used in the United States to prevent cracks in the substrate from being reflected through overlays. It is normally applied as either a chip-seal surface treatment with approximately 20 percent rubber added to the asphalt, commonly known as a stress-absorbing membrane, or as an interlayer of rubber-asphalt binder and aggregate (stress-absorbing membrane interlayer) overlaid by a thin course of asphaltic concrete.

In Australia, the main use of the scrap rubber-asphalt digestions has been in sprayed surface treatments where the advantages are considered to be

1. The sealing of cracked pavements to prevent, or delay the onset of, reflection cracking, and
2. The retention of chips in hot weather under severe traffic stress conditions (such conditions occur when seals are used to provide surface texture on high-speed roads where a conventional asphalt seal is unable to provide satisfactory stone retention at bends or in acceleration and deceleration areas).

DEFORMATION TESTING OF RUBBER-MODIFIED ASPHALTS

Sinusoidal Loading

A useful means of evaluating the deformation behavior of asphalts and rubber-modified asphalts is by their response to sinusoidal loading in simple shear. This provides basic information on the behavior of the materials, but specialized equipment is required and testing is slow. The sinusoidal loading procedure was therefore used only to determine the appropriate test conditions (temperature, rate of strain, etc.) for the rubber-asphalt digestions, and a simpler apparatus, operated near the required conditions, was then used for routine testing.

In the sinusoidal loading procedure, a force applied to the material produces a sinusoidal displacement that lags behind the force (see Figure 1). The magnitude of the phase-angle difference between the force and the displacement (ϕ) is an indication of the partitioning of the response between viscous and elastic behavior. The phase angle is zero for purely elastic behavior and 90° for purely viscous behavior. The ratio of the maximum value of the force to the maximum value of the displacement is proportional to the complex

Figure 1. Deformation response of viscoelastic material to repeated sinusoidal loading.

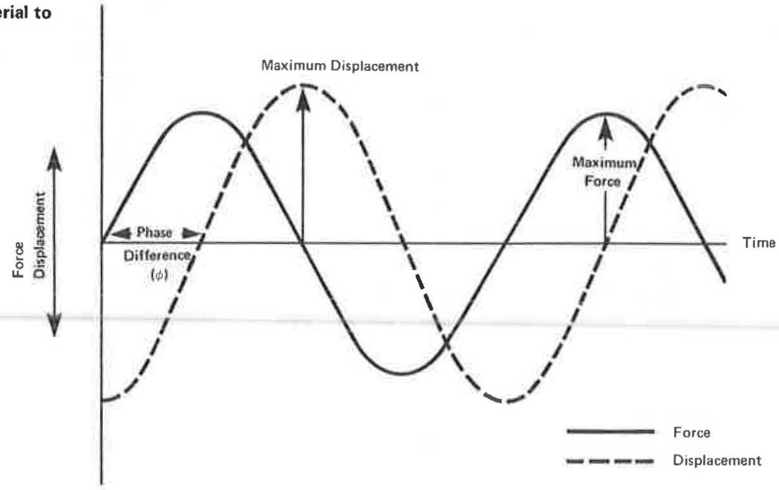
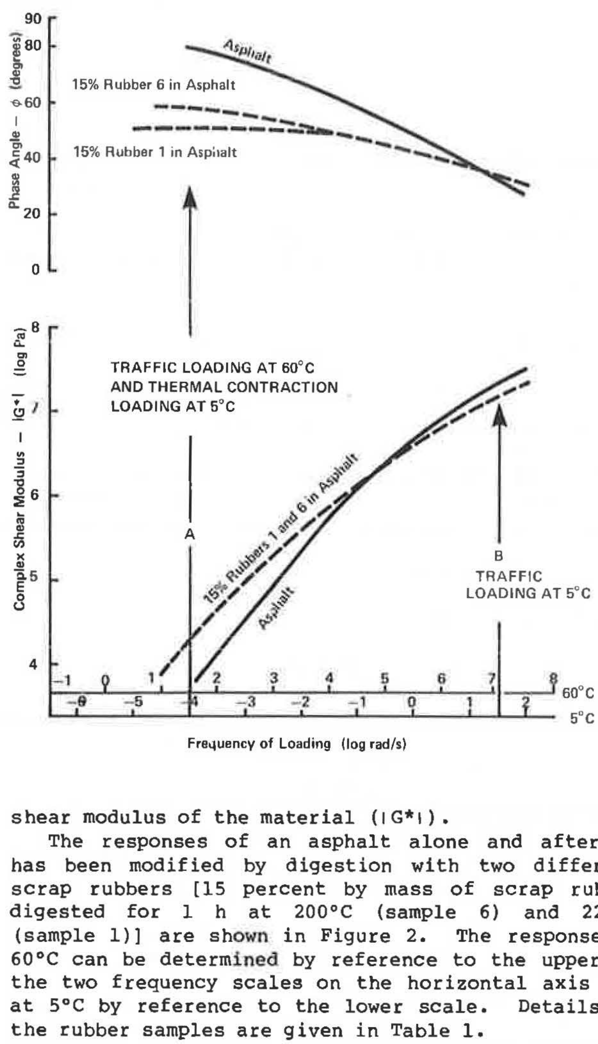


Figure 2. Modification of viscoelastic response of asphalt at 5° and 60°C by digestion with scrap rubber.



shear modulus of the material (|G*|).

The responses of an asphalt alone and after it has been modified by digestion with two different scrap rubbers [15 percent by mass of scrap rubber digested for 1 h at 200°C (sample 6) and 220°C (sample 1)] are shown in Figure 2. The response at 60°C can be determined by reference to the upper of the two frequency scales on the horizontal axis and at 5°C by reference to the lower scale. Details of the rubber samples are given in Table 1.

Sample 6 has depressed the increase of the phase angle at low loading frequencies to a constant value just below 60°. Sample 1 is even more effective, reducing the angle to about 50°. At these very slow rates of strain or high temperatures, the response of the unmodified asphalt is that of a viscous liquid, whereas the modified binders show behavior typical of a low-modulus elastic solid.

Table 1. Samples used in bulk-density test.

Sample	Rubber Composition	Preparation Method
1	Synthetic	Industrial tire grinding
2	Synthetic	Laboratory drilling of tire tread A
3	Synthetic	Laboratory rasping of tire tread B
4	Synthetic	Laboratory rasping of tire tread C
5	60 percent synthetic	Laboratory drilling of tire tread D
6	Synthetic	Tire retreader's buffings
7	Synthetic	Laboratory drilling of tire tread C
8	Synthetic	Industrial cryogenic
9	Synthetic	Laboratory cryogenic
10	Natural	Laboratory rasping of tire tread E
11	Natural	Laboratory drilling of tire tread E
12	Natural	Industrial tire buffings
13	Natural	Undisclosed industrial process
14	Natural	Laboratory cryogenic
15	Natural	Undisclosed industrial process

Relation to Pavement Loading

Two kinds of loading are of particular importance in relation to the performance of thin bituminous surfacings. The first, due to vehicles passing over the surfacing, is assumed to be periodic and has a loading time of between, say, 20 and 50 ms, depending on vehicle speed. The second, due to thermal contraction by diurnal temperature change, has a duration of the order of 10^4 s. The magnitude of the strains produced in the binder by such loading is not known precisely, but the high-stress locations in the surfacing are where the binder films are thin (3). In such locations, the strain in the binder will be high.

Vehicle loading can cause distress in a surfacing at either end of the range of pavement surface temperatures. At high pavement temperatures, the binder can be too fluid and not resist the plucking and shearing action of vehicle tires; at low pavement temperatures, the binder can be so hard (particularly after a long period of service) that vehicle loading causes brittle fracture of the binder films. Thermal-contraction loading is critical at low pavement temperatures when the binder (again, particularly after long-term exposure) is at its hardest. Since both modes of loading induce overall, gross tensile strains in the surfacing, they will augment each other to produce the cracking that eventually occurs at low surface temperatures.

These important rate-of-loading conditions at the appropriate pavement temperatures for Australian conditions are given in Table 2 and are indicated by arrows A and B in Figure 2.

Selection of Test Procedure and Test Conditions for Rubber-Modified Asphalts

Consideration of Figure 2 indicates that the important modification of deformation response by the addition of scrap rubber, so far as performance in the pavement surfacing is concerned, is for traffic loading at high road temperatures and thermal contraction at low road temperatures (arrow A). For traffic loading at 5°C (arrow B), there is no significant change in the phase angle or modulus level.

To compare the effectiveness of different scrap-rubber digestions in asphalt, it is desirable to have a simple and rapid method of evaluating the deformation response of the product. To assess the relative benefit in pavement service, such testing should be done at about 60°C, at a rate of loading equivalent to traffic loading and to relatively high strains.

A simple method of measuring creep and elastic recovery in shear was developed by using a modification of the Shell sliding-plate rheometer. This instrument enables a higher strain (1.0) to be realized than is possible with sinusoidal loading and permits rapid testing at the test temperature selected (60°C).

The above discussion indicates the desirability of using test methods that indicate the basic deformation and flow behavior of the rubber-asphalt digestions under the critical pavement service conditions. These materials have properties intermediate between those of asphalt and those of rubber, and empirical procedures used to evaluate asphalts may not be suitable. The deformation behavior of rubber-modified asphalts and methods of testing are discussed in greater detail by Dickinson (4).

EXPERIMENTAL PROGRAM

Digestion Procedure

The primary method of evaluation of different rubber-asphalt systems was the laboratory digestion, under controlled conditions, of mixtures of the comminuted scrap rubber and asphalt followed by deformation testing of the product. The laboratory digestion procedure required that the rubber sample be dried in a vacuum oven prior to addition to the hot asphalt in a reaction flask maintained at the desired temperature. The mixture was continuously stirred, and samples were withdrawn and cast, when hot, into sliding-plate rheometer test molds.

Laboratory digestion simulates the heat treatment applied prior to spraying of the product in road construction operations. In Australia, this normally takes the form of circulation of the materials in an asphalt sprayer at about 200°C for between 30 min and 1 h (5).

Deformation Testing of Digestions

An extensively modified sliding-plate rheometer was used to measure the deformation properties (creep in shear) of the binder specimens. A diagram of the apparatus is shown in Figure 3. Although the instrument is simple to use, it is necessarily delicate and is more suited to research needs than to routine quality-control work.

To test a sample, a mass of 20 g was applied to a 10-mm-thick specimen until a strain of 1.0 was obtained. The load was then automatically removed by a motor-driven mechanism, and the sample was permitted to recover under a "no-load" condition. Movement of the free plate was recorded by using a displacement transducer.

The parameters calculated for analysis were time under stress (i.e., time to reach a strain of 1.0) and percentage elastic recovery (defined as the percentage of this strain recovered when the load is removed and after a recovery period that is 10 times the straining period). Time under stress can be regarded as a simple measure of resistance to deformation at the test temperature (60°C), whereas elastic recovery is an indication of the elastic component of this deformation.

Normally, a particular asphalt-rubber combination was digested for 2 h in the reaction vessel at a controlled temperature. Samples were removed for testing after digestion for 0.5, 1, and 2 h. Three

Figure 3. Diagram of apparatus used to measure elastic recovery of strain.

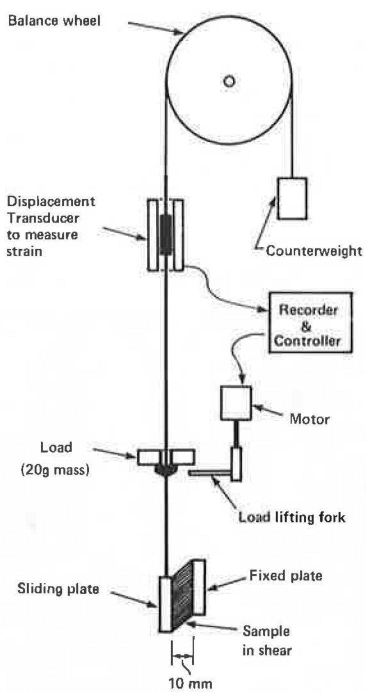


Table 2. Rate of loading conditions for bituminous surfacings.

Loading Mode	Surfacing Temperature	Loading Duration (s)	Approximate Frequency of Sinusoidal Loading (log rad/s)	Distress Mode
Moving traffic	High 60°C[a]	0.02-0.05	+1.5	Shearing and plucking of aggregate
	Low 5°C[b]	0.02-0.05	+1.5	Brittle fracture of binder films
Thermal contraction	Low 5°C[a]	10^4	-4.0	Cracking of surfacing

[a]Arrow A, Figure 2. [b]Arrow B, Figure 2.

specimens were prepared from material removed after each digestion time. A test result is the mean value obtained for these three specimens. Repeat testing on an asphalt-rubber combination, which was relatively insensitive to changes in time and temperature of digestion, indicated that the confidence limits (95 percent probability) of a test result were ±1.4 s for time under stress and ±3.1 percent for elastic recovery.

Materials Evaluated

Two asphalts representative of Australian production were used. Both were 85/100 penetration grade. The material used for the bulk of the testing was the vacuum distillation residue from Kuwait crude petroleum, air-blown to grade. The second asphalt, which was more aromatic in character, was a blend of the vacuum distillation residue from a Kuwait crude petroleum and the propane-precipitated asphalt from this residue.

The bulk of the rubber granulate used for asphalt work in Australia is the material produced during the preparation of used tires for retreading. A series of rotating saw blades contact the tread area of the tire, and the buffings are drawn off by a vacuum system. Normally, the buffings supplied for asphalt work are a mixture of natural (truck-tire) and synthetic (car-tire) rubbers, the car-tire rubber predominating.

Products from two other comminution processes supply the remainder of the asphalt market. One of these is the cryogenic method, which involves hammer milling of the rubber after it has been cooled with liquid nitrogen. At a sufficiently low temperature, the rubber behaves as a brittle solid. Another process, for which full details have not been disclosed, involves softening and swelling of the tire by solvent immersion followed by size reduction and solvent recovery.

Industrially produced scrap-rubber particles can be of variable and indeterminate composition. As part of the study, comminuted rubber prepared from cured sheets of vehicle-tire feedstock of known composition were examined. The laboratory comminution processes used included rasping, drilling, hand cutting, and cryogenic embrittlement followed by crushing.

RESULTS

Rubber Particle Morphology

The gross morphology (structure) of the rubber particles, as determined by the way they are produced, was found to be the most important factor affecting the elastic properties of the rubber-asphalt digestions. The difference in the morphology of particles produced by three different processes is clearly illustrated in the scanning electron photomicrographs produced in Figures 4-6. The particles shown all passed a 600-μm sieve and were retained on a 300-μm sieve when sieved dry. A summary of the appearance of the particles and their composition and production method together with the elastic recovery value of an asphalt digestion of each sample is given in Table 3.

Examination in the scanning electron microscope of rubber particles produced by a number of processes indicated that there are two main types of morphology: one where the surface is covered in porous, "spongelike" nodules and one where the surface is smooth. These two extremes are shown by the photographs in Figures 4 and 6, respectively. Particles with intermediate morphology generally have either a smooth surface with some porous nodules attached or a mixture of smooth and nodular-surfaced particles.

There appeared to be a relation between the number of porous nodules present in a sample and the elastic recovery of strain of a digestion of the sample in asphalt. Accordingly, a simple means of characterizing particle morphology was devised, and the relation between this property and elastic recovery of strain was examined. The property measured was the bulk density in water of particles

Figure 4. Electron micrograph of laboratory-ground synthetic tire-tread rubber.

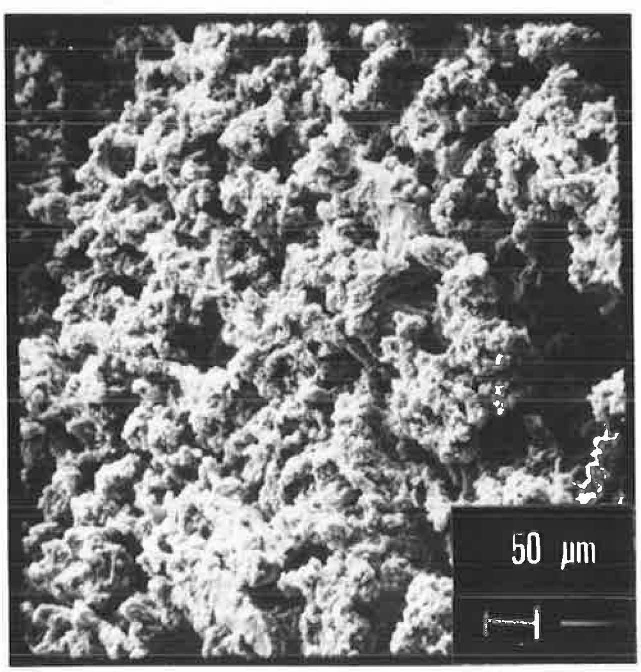


Figure 5. Electron micrograph of laboratory-drilled synthetic tire rubber.

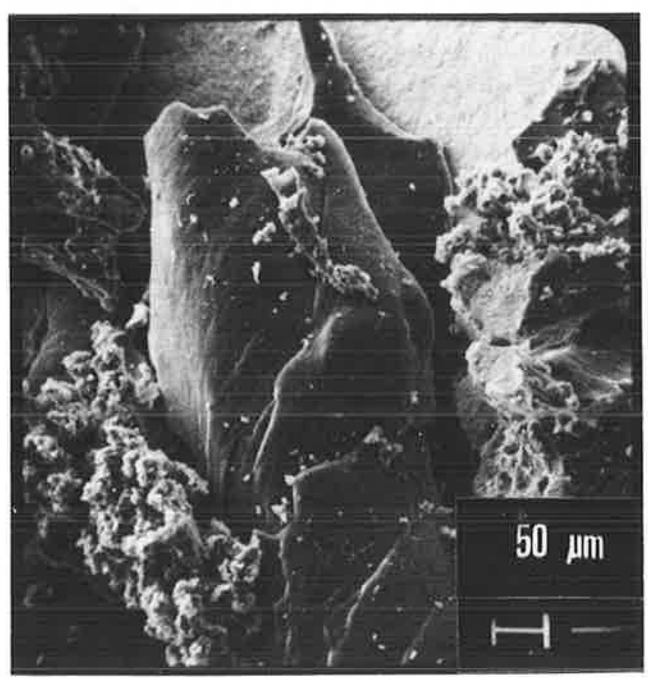


Table 3. Properties and appearance of samples shown in Figures 4-6.

Figure	Material and Production Process	Gross Morphology	Elastic Recovery[a] (%)
4	Laboratory-produced car-tire grindings	Particle surface completely covered with porous nodules	35
5	100 percent styrene-butadiene, cured tire feedstock, laboratory drilled	Generally smooth, rounded particles with a few porous nodules attached	17
6	100 percent styrene-butadiene, cured tire feedstock, embrittled in liquid nitrogen and crushed	Smooth-faced, angular, cracked particles	3

[a]Fifteen percent by mass rubber in air-blown asphalt digested at 200°C for 0.5 h.

Figure 6. Electron micrograph of cryogenically crushed synthetic tire rubber.

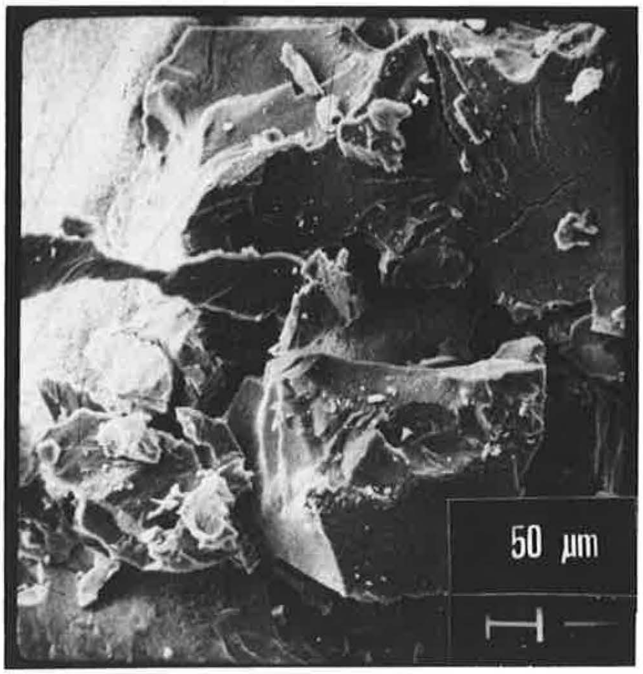
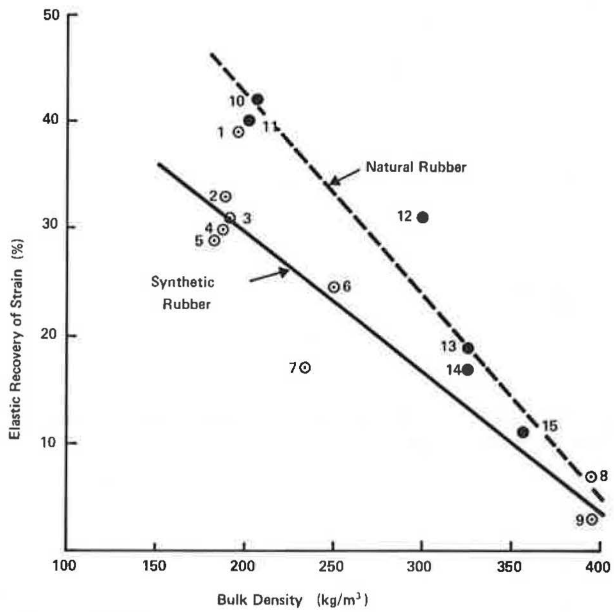


Figure 7. Relations between elastic recovery and bulk density for natural and synthetic rubbers.



separated between the 300- and 600-µm sieves (6).

To determine the bulk density, 7.5 g of sieved rubber particles was first boiled in 100 mL of water to remove trapped air, and then a weak detergent solution was added to ensure reproducible wetting of the particles. The volume of the rubber was measured after the sample had been allowed to settle in the water for 15 min. Replicate testing indicated that the confidence limit at the 95 percent probability level of the mean of two tests was ±8.2 kg/m³.

The relation between percentage elastic recovery (0.5-h digestion at 200°C of 15 percent by mass rubber in the air-blown asphalt) and bulk density is shown in Figure 7 for a number of rubbers. The desirable condition, for pavement service, is for the rubber-asphalt digestion to show a high value of elastic recovery. The rubber samples are identified by specimen number, and brief details of their composition and method of preparation are given in Table 1. Separate regression lines are drawn for natural and synthetic rubbers. The Pearson correlation coefficient is 0.96 for natural rubbers and 0.93 for synthetic rubbers.

The results show that there is a strong correlation between particle morphology (as measured by the bulk-density test) and the elastic recovery of strain of the rubber-asphalt samples. The digestion conditions used are the ones most commonly used for spraying of rubberized binders in Australia.

Digestion Conditions

The effect of time and temperature of digestion on the elastic recovery of synthetic and natural rubber-asphalt digestions, made from industrially produced rubber buffings, is shown in Figures 8 and 9. For both rubber types, elastic recovery increases with both time and temperature of digestion up to 220°C. At 240°C, there is no further increase for the 2-h synthetic rubber digestion and a marked reduction in elastic recovery for the 1- and 2-h natural rubber digestions. Figure 10 shows the time-under-stress results for natural rubber. These results suggest that, with this rubber, thermal degradation can occur at temperatures as low as 180°C but that the elastic properties of the mixture are not immediately affected. The synthetic rubbers tested generally had a time-under-stress value of between 5 and 10 s regardless of digestion conditions.

The significance of these results, with regard to asphalt spraying operations, is that both natural and synthetic rubbers behave satisfactorily under normal digestion conditions in the sprayer. However, if overheating occurs, the properties of natural-rubber digestions are more rapidly degraded than are those of synthetic-rubber digestions. Since time and temperature of digestion are interdependent, the same difficulty can arise from extended digestion times at normal spraying temperatures.

Rubber Composition

Results presented in the previous sections indicate

Figure 8. Effect of time and temperature of digestion on elastic recovery for synthetic-rubber tire buffings.

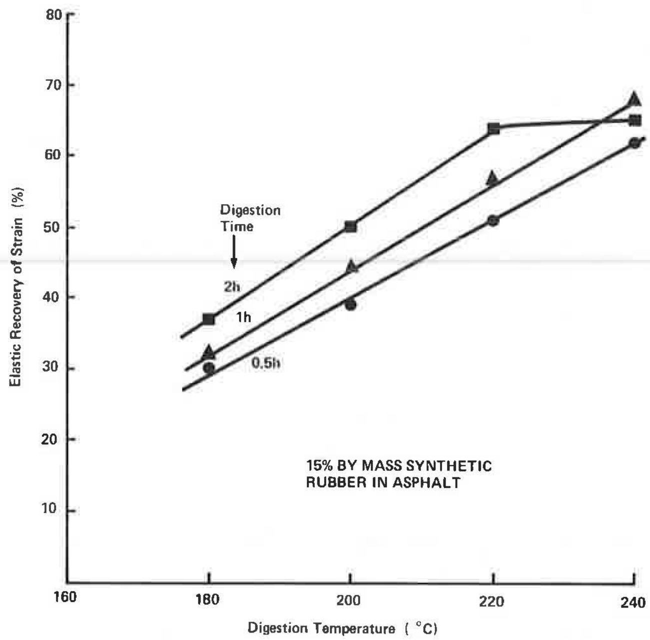
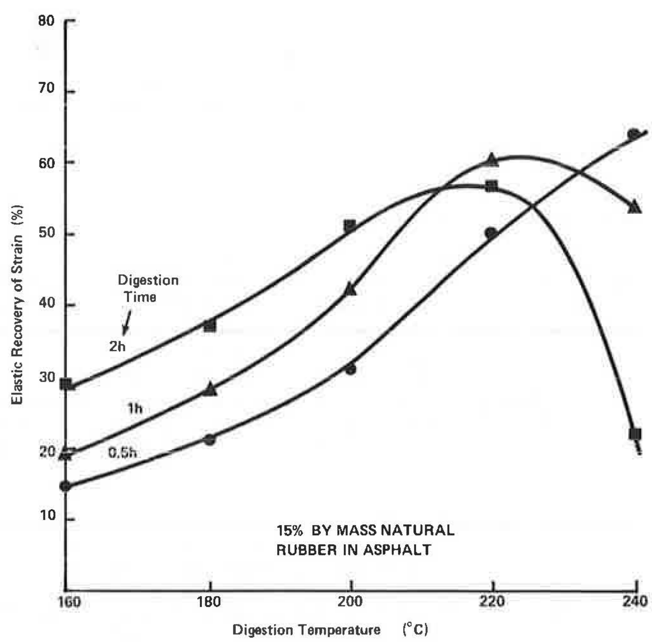


Figure 9. Effect of time and temperature of digestion on elastic recovery for natural-rubber tire buffings.

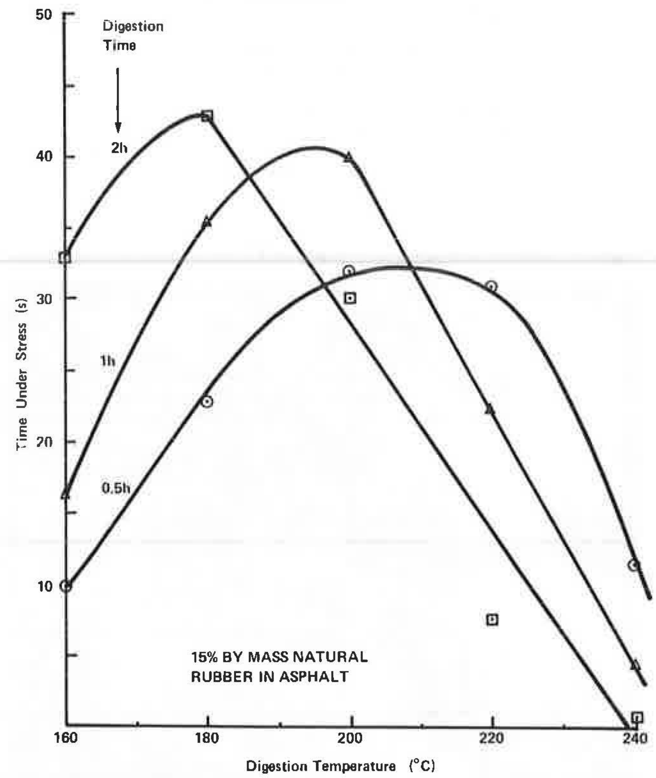


that rubber composition is an important variable that interacts with both particle texture and digestion conditions. As an example, digestions of cryogenically prepared natural rubber improved significantly (in terms of elastic recovery) as digestion time increased, whereas digestions of cryogenically prepared synthetic rubber did not.

Rubber Concentration

The effect of rubber concentration on elastic recovery of strain is shown in Figure 11 for typical spraying conditions (tire retreader's buffings

Figure 10. Effect of time and temperature of digestion on consistency of digestions of natural-rubber tire buffings.



digested in air-blown asphalt at 200°C).

Linear relations, with correlation coefficients of 0.99, apply for the three digestion periods studied. Linear relations were also found to apply for a high-elastic-recovery material that could, however, only be tested over a narrow concentration range because the highest-concentration samples were impossible to pour.

Rubber Particle Size

For tire retreader's buffings (mainly synthetic), there was a small, regular increase in elastic recovery as particle size decreased. This may be due to the smaller-sized fractions containing a higher proportion of porous (low-bulk-density) particles than the larger-sized fractions. In the case of cryogenically prepared synthetic rubber, there was very little modification of the parent asphalt properties even when a sample of the rubber was reduced in size so that it all passed a 150-μm sieve and 25 percent passed a 75-μm sieve.

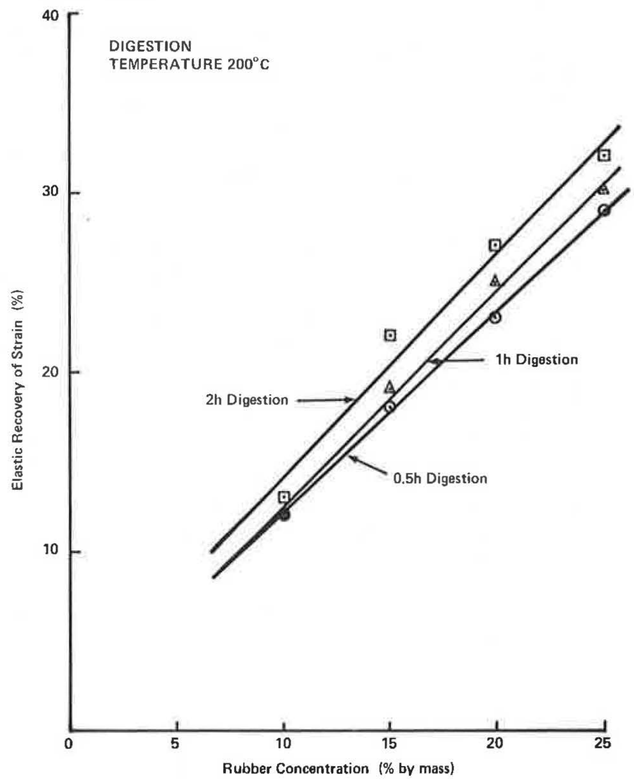
Bitumen Composition

There was no significant difference between the air-blown and the propane-precipitated Kuwait asphalt in respect to elastic recovery of strain. This was true for both natural and synthetic rubber specimens and for rubber particles with a porous (low-bulk-density) or a smooth (high-bulk-density) appearance.

Curing of Rubber-Asphalt Binders After Application

To determine whether structural changes can occur in rubber-asphalt binders after they have been sprayed, the behavior of specimens during extended laboratory storage was observed. A storage temperature of 55°C was selected as typical of the maximum surface

Figure 11. Rubber concentration versus elastic recovery.



temperature likely to be encountered and to ensure that any changes that occurred did so at a detectable rate.

Two rubber samples were used: industrial retreader's buffings and new-car-tire buffings. These were typical of rubber samples that gave a low and a high elastic recovery. Each sample was used to prepare specimens digested at (a) conditions that gave optimum elastic recovery and (b) conditions that gave below-optimum elastic recovery. For both sets of samples and conditions, there was little or no change in elastic recovery with time of storage.

DISCUSSION OF RESULTS

The main factors that affect the behavior of rubber-asphalt digestions have been identified and studied. However, the list is by no means exhaustive and there may be others, such as rubber particle shape and the "nonrubber" additives in tire rubber, which could be important.

The morphology of the rubber particles has been shown to play an important role in determining the properties of rubber-asphalt digestions. The form of the particles seems to be determined by the disintegration method used. Tearing apart the bulk rubber at near-ambient temperatures so that stretching of the rubber takes place before fracture produces a much more "active" material than brittle fracture at low temperatures. Experimentation with different manufacturing procedures is planned in order to obtain low-bulk-density products.

Production by the cryogenic process appears unsatisfactory, particularly for predominantly synthetic rubber materials. Either further treatment of the product is required, or this method of comminution should be restricted to natural rubber scrap.

The bulk of scrap rubber used in asphalt is predominantly synthetic, and digestion conditions are not particularly critical. If a low-bulk-density product were to be introduced, smaller concentrations might be as effective as high concentrations of currently used scrap rubbers. Digestion conditions could, however, become more important, and this would certainly be true if the product contained a high percentage of natural rubber. There is a need for a simple quality-control test to evaluate the deformation properties of rubber-asphalt digestions. In the interim, the bulk-density test and analysis of the composition of the rubber can be used as a guide to quality.

A separate test will be needed to indicate whether improved digestions can be sprayed by using conventional equipment and procedures. If spraying of these materials proves to be difficult, such a test could be used to evaluate the effectiveness of measures designed to improve sprayability. Since the process of forcing a viscoelastic fluid through an orifice under pressure to produce a regular flow pattern is not well understood, the best approach may be to simulate the field spraying condition in the laboratory. An apparatus has been constructed that allows rubber-asphalt digestions to be sprayed from a regular slotted jet nozzle at the pressure and temperature used in road sprayers. This apparatus will be commissioned shortly.

In Australia, as the demand for scrap rubber has increased, so has the price. It is possible that specially formulated synthetic polymers may soon become competitive. Dispersions in asphalt of one group of these materials, known as block copolymers, have the advantage of having very little effect on the asphalt at spraying temperatures but developing marked rubberlike properties through the formation of a network structure at service temperatures. New types of block copolymers are coming onto the market, and these should be evaluated to determine the minimum effective concentration in asphalt.

There is little information on the long-term durability of rubber-asphalt digestions, although they have given satisfactory service in Australia for more than five years now. Laboratory durability tests developed for asphalts (7) may not be appropriate for this type of material, but there could be a need to determine whether these modified asphalts maintain their elastic behavior under the long-term exposure of pavement service.

Road trials are planned in Australia to investigate the effect of concentration and type of rubber on long-term service performance of sprayed seals, both in high-traffic-stress situations and as overlays for cracked pavements.

CONCLUSIONS

Modification of asphaltic cements by use of scrap rubber improves deformation response under traffic loading at high pavement temperatures and loading due to thermal contraction at low pavement temperatures. A simple and rapid laboratory test procedure was developed to assess the degree of improvement obtained from various rubbers and digestion procedures. This procedure is as near as practicable to the loading and straining conditions described above.

The major findings for digestions of scrap tire rubber in asphalt were as follows:

1. Rubber particle morphology, as determined by the process used to manufacture the particles, is the most important of the factors that affect the elastic properties of rubber-asphalt digestions. This morphology can be characterized by a simple bulk-density test.
2. Natural-rubber digestions tend to be superior

to those containing synthetic rubber, but digestion conditions (time and temperature) are less critical for synthetic rubber.

3. The elastic recovery of strain of the digestions is linearly related to the rubber concentration.

4. For car-tire retreader's buffings, the elastic recovery of the digestions tends to increase as the size of the rubber particles used decreases.

5. Little or no change in the elastic recovery of certain specimens was observed when they were stored at 55°C (which imitated curing over an extended period in road service).

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This paper is presented with the permission of the executive director of the Australian Road Research Board. Views expressed in the paper are solely my own.

REFERENCES

1. C.H. McDonald. A New Patching Material for Pavement Failures. HRB, Highway Research Record 146, 1966, pp. 1-16.
2. G.R. Morris and C.H. McDonald. Asphalt-Rubber Stress-Absorbing Membranes: Field Performance and State of the Art. TRB, Transportation Research Record 595, 1976, pp. 52-48.
3. E.J. Dickinson and H.P. Witt. The Deformation Behaviour of Thin Films of Asphalt Confined Between Rigid Surfaces and Subjected to Rates of Loading Simulating Traffic Over a Pavement. Division of Petroleum Chemistry, American Chemical Society, Symposium on Science of Asphalt in Construction, preprint, Vol. 16, No. 1, 1971, pp. D156-D164.
4. E.J. Dickinson. Assessment of the Deformation and Flow Properties of Polymer-Modified Paving Bitumens. Australian Road Research, Vol. 11, No. 3, 1981, pp. 11-18.
5. J.D. Bethune. Use of Rubber in Bituminous Surfacing. Proc., 9th Conference of Australian Road Research Board, Vol. 9, No. 3, Session 24, 1978, pp. 9-32.
6. J.W.H. Oliver. A Bulk Density Test to Characterize the Morphology of Rubber Particles. Australian Road Research Board, Vermont, Victoria, Internal Rept. AIR 286-3, 1981.
7. E.J. Dickinson. The Hardening of Middle East Petroleum Asphalts in Pavement Surfacings. Proc., AAPT, Vol. 49, 1980, pp. 30-63.

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Effect of Aggregate Top Size on Asphalt Emulsion Mixture Properties

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Since base-course aggregate gradations have top sizes larger than 25.4 mm (1 in) in most cases, the adequacy of using the standard Marshall procedure in evaluating asphalt-stabilized base courses has been questioned. The findings of a comprehensive laboratory investigation that focused on the evaluation of the effect of aggregate top size on the Marshall test results of cold-mixed asphalt emulsion mixtures are reported. Marshall specimens were prepared by using a high-float asphalt emulsion, HFMS-2s, and aggregate top sizes of 19 and 38 mm (0.75 and 1.5 in). Other factors included in the study were asphalt emulsion content, aggregate type, and aggregate gradation. Marshall tests were performed at 22°C (72°F) to evaluate the mixture properties. Test results for such factors as stability, flow, stiffness, and index were obtained. Other mixture properties, such as specific gravity, air voids, retained moisture, and total liquid, were also evaluated. According to the test results, increasing the aggregate top size in the asphalt emulsion mixture from 19 to 38 mm increased the bulk specific gravity and decreased the air voids. The retained moisture and total liquid in the mixture after curing were not largely affected by the aggregate top size. The modified Marshall test results were altered to some extent by the change in aggregate top size. It is recommended that the effect of aggregate top size be taken into consideration when the standard Marshall procedure is used in designing asphalt emulsion mixtures with large aggregate top sizes.

In recent years, a great deal of interest has been shown in, and much effort has been devoted to, the development of various types of stabilized materials for use in pavement construction. The use of asphalt emulsions as stabilizing agents has increased tremendously in the past two decades, precipitated by apparent economic and environmental benefits (1). Asphalt emulsions can be mixed at ambient temperatures, which saves both the cost and amount of fuel needed for hot mixes. Asphalt emulsion mixtures also eliminate the dust and combustion pollutants that result from the drying and mixing of the aggregate. In spite of their widespread use, the behavior of these mixtures has not been sufficiently well understood to enable the development and acceptance of a rational design procedure and set of criteria (2).

According to the standard preparation procedure of Marshall specimens [102 mm (4 in) in diameter by 64 mm (25 in) high], the aggregate top size should not exceed 25.4 mm (1 in). Since base-course aggregate gradations frequently have top sizes greater than 25.4 mm, the adequacy of the standard Marshall procedure in the design of asphalt-stabilized base courses has been questioned. This study reports the findings of a comprehensive laboratory investigation that focused on the evaluation of the effect of aggregate top size on the Marshall test results of cold-mixed asphalt emulsion mixtures. Two aggregate top sizes were used: 19 and 38 mm (0.75 and 1.5 in). One asphalt emulsion type, three asphalt emulsion contents, two aggregate types, and two aggregate gradations were included in the study. A modified Marshall test was used in the evaluation process. Marshall test results such as stability, flow, stiffness, and index were obtained at a test temperature of 22°C (72°F). Other mixture properties, such as specific gravity, air voids, and retained moisture, were also evaluated.