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IMPROVEMENTS IN ROLLED ASPHALT SURFACINGS BY THE ADDITION OF ORGANIC POLYMERS

by

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ABSTRACT

The report discusses the use of various organic polymers to improve the properties of bituminous binders, and describes the effects of these improvements on the resistance to permanent deformation, dynamic stiffness and laboratory fatigue life of rolled asphalt wearing courses.

Emphasis has been placed on improving resistance to permanent deformation to meet the demand for better surfacing materials for very heavily trafficked roads. Of the materials investigated so far, a copolymer of ethylene and vinyl acetate (EVA) was found to be the most effective and simplest to use. Binders containing EVA also improved the dynamic stiffness of rolled asphalt without adversely affecting laboratory fatigue behaviour. Workability during mixing and laying was also improved.

Measurements of the effects of EVA and other polymers, such as epoxy resins and elastomers, on the structural properties of rolled asphalt, and the correlation of some of these properties with those of the binder, have also provided a basis for assessing the potential benefits of using these polymers in other types of bituminous material.

1. INTRODUCTION

Over the years many additives have been investigated with the aim of improving the rheological properties of bitumen and tar, but few have found a permanent place in road engineering practice. There are several reasons for this. Improvements in the rheological properties of the binder have often not been reflected in road performance and sometimes additives have introduced more problems than they have solved. Additional processing of the binder or mix and restrictions on traditional handling and laying techniques are typical examples of the difficulties incurred by using additives. Such problems have made it very difficult to demonstrate that additives can improve road performance consistently and to a degree sufficient to justify the extra cost or inconvenience involved.

The advent of new additives and ideas and a need for higher quality bituminous materials to cope with the growing demands of heavy traffic made a further examination of the potential benefits from additives such as sulphur and organic polymers worthwhile. Research on the use of sulphur has already been reported[1,2]. The present report describes the results obtained with organic polymers.

2. OBJECTIVES

On the majority of our road network conventional bituminous materials perform satisfactorily but for certain special applications or where traffic is extremely heavy, better materials are required; examples are rolled asphalt wearing courses with a high resistance to permanent deformation, bridge deck surfacings with improved resistance to cracking and roadbase materials with greater stiffness and strength. The overall objective of the present work is to assess the potential of polymer additives as a means of achieving these improved properties. Attempts have also been made to correlate the properties of binders with those of the mixed materials.

It was decided to concentrate initially on producing or identifying binders that would increase the resistance to permanent deformation of rolled-asphalt wearing-courses. There are, of course, other ways of improving rolled asphalt in this way and the use of additives has not been studied in isolation[3]. One alternative is to use heavy duty bitumens, and the properties and effects of these binders have been studied alongside those of additives to provide a better perspective for assessing any improvements.

Although the work described here has been restricted to rolled-asphalt wearing-course mixtures, in which resistance to permanent deformation is the most important structural property, measurements of the effects of additives were not confined to those concerned purely with this property. Their effects on dynamic stiffness and laboratory fatigue life have also been measured and this work, together with that on the properties of the binders themselves, has provided a basis for assessing the value of extending the use of additives to other types of bituminous materials.

3. THE ROLE OF POLYMERS IN BITUMINOUS MATERIALS

Because the binder is responsible for the visco-elastic behaviour characteristic of all bituminous materials, it plays a large part in determining many aspects of road performance. Resistance to permanent deformation is a typical example. In general the proportion of any induced strain that is attributable to viscous flow (non-recoverable) in a bituminous material, increases with both loading time and temperature. Not surprisingly, therefore, ruts develop more rapidly at high temperatures and where traffic moves slowly or stops. Such deformation is often distributed through all the layers of a bituminous pavement, but a large proportion of it usually occurs in the wearing course because it is here that the combined effects, in terms of temperature and traffic loading, are likely to be most severe. In Britain road surface temperatures range from below zero to 50, or even 60°C on rare occasions. The vertical stresses generated in a wearing course by a rolling wheel have loading times that range from around 10^2 seconds, where vehicles pause at junctions, to about 10^{-2} seconds where they are travelling at speed.

The primary role of a polymer additive, therefore, is to increase resistance to permanent deformation at high road temperatures (or long loading times) without adversely affecting the properties of the binder or asphalt at other temperatures. However, as an improvement of this kind is likely to be the result of the polymer improving either the stiffness or the elastomeric properties of the binder, secondary benefits in terms of better load spreading ability or flexibility may accrue.

4. PROPERTIES REQUIRED IN POLYMER ADDITIVES

For a polymer to be effective in the role outlined in Section 3, and for its use to be both practicable and economic, it must:–

i) Be readily available.
ii) Resist degradation at asphalt mixing temperatures.
iii) Mix easily with bitumen.
iv) Improve resistance to flow at high road temperatures without making the binder too viscous at mixing and laying temperatures or too stiff or brittle at low road temperatures.

v) Be cost effective.

Requirement (iv) is not only the most crucial but also the most difficult to satisfy. In tackling this problem the following considerations were borne in mind.

The rheological properties of bitumen or tar depend on an energy balance. Thermal energy is responsible for the translational, vibrational and rotational movements of molecules. Intra- and intermolecular forces and entanglement coupling effects oppose these movements and together comprise a form of internal friction. Therefore, the balance between thermal energy and internal friction determines the freedom with which the molecules of the binder can move, allowing it to flow or deform in response to external stress. Only by changing this balance can the desired improvements in rheological properties be made.

In attempting to do this the use of both thermosetting and thermoplastic polymers has been investigated.

5. THERMOSETTING POLYMERS

These usually consist of two components, resin and hardener, which can increase the strength of bituminous binders many times over by reacting chemically to form a three-dimensional structure. This structure can, to a great extent, override the effects of thermal energy at road temperatures because this energy is much lower than that required to break the chemical bonds in the hardened resin structure. The main disadvantages of this type of polymer are that they tend to be expensive and have to be added in large quantities.

Research to date has concentrated on blends of epoxy resin with bitumens and tars. Emphasis has been placed on keeping the resin content to a minimum and in this respect the blends with tar were more successful primarily because tar is more compatible than bitumen with epoxy resin. Even so, a minimum of 15 to 20 per cent of resin was needed to make a worthwhile improvement. This probably makes this type of binder too expensive for all but very special applications where there are stringent requirements in addition to a high resistance to deformation. But there is no doubt that rolled asphalt modified in this way has remarkable properties; asphalt containing a commercially available binder modified with around 30 per cent of epoxy resin, had a wheel-tracking rate of almost zero at 45°C and a complex modulus about 10 times that of conventional rolled asphalt at 33°C and a test frequency of 10 Hz. These properties are described again in Section 6.3.3 and illustrated in Figure 4.

Several factors contributed to the need for a relatively high resin content. A viscous medium like bitumen inhibits the reaction between molecules of resin and hardener because it reduces their chances of colliding. The only way to offset this, and to produce a controlled reaction, is to have sufficient concentrations of resin and hardener. Increasing the temperature would accelerate the reaction, but even at normal asphalt mixing temperatures the reaction rate is often so fast that the asphalt stiffens before it can be laid. Consequently, a lower than normal mixing temperature is essential with most resin systems, but this is only possible if the components of the binder also have correspondingly lower initial viscosities to enable the aggregate to be thoroughly coated. Immediately, therefore, some of the benefit from the polymer is lost in bringing the stiffness of the binder up to that of a conventional one before any net improvement is conferred. Achieving the high degree of cross-linking necessary to give a substantial net improvement inevitably leads to higher resin contents. Without some major development to overcome these problems, there would appear to be no way of formulating a successful binder with a very low resin content.

6. THERMOPLASTIC POLYMERS

As there is no chemical cross-linking between the molecules of thermoplastic polymers, they rely on secondary valence forces and entanglement coupling for their cohesive strength. Although these forces are similar in magnitude to those resulting from thermal energy at road temperatures, they can still be used to give the improvements desired in the rheological properties of bitumens and tars.

Many polymers are sufficiently compatible with these binders to increase their resistance to flow. Polymers that combine properties such as high molecular weight, a high degree of steric hindrance or structural regularity and a high energy of molar cohesion should, in general, give the largest increases. But these are unlikely to be confined to high road temperatures, and the effect on the properties of rolled asphalt may be little different from that obtained by using a harder grade of conventional binder. If the modulus of the binder is increased substantially at low temperatures the flexibility and fatigue properties of the asphalt could be adversely affected.

Polymers likely to confer flexibility at low road temperatures have properties that contrast with those outlined above. Their molecules, or at least some sections of them, are bound by weak forces that allow them to move quickly and easily to comply with an applied stress. In bitumen these polymers tend, therefore, to reduce modulus and increase resilience together with the ability to accommodate large strains. Such behaviour is typical of elastomers, and if some cross-linking between their molecules is introduced both resilience and modulus at high strains can be increased substantially. The net effect on the resistance to permanent deformation of asphalt is likely to depend on whether or not the positive effect of increasing resilience is cancelled out by the reduction in modulus, which would lead to higher strains in the asphalt in the road.

Therefore the solution to the primary problem of increasing resistance to permanent deformation of rolled asphalt without making it substantially stiffer or brittle at low road temperatures is likely to come from modifying the binder either with more than one polymer, or with a copolymer that combines at least some of the properties required.

6.1 Types of polymers investigated

In the course of research to develop improved binders for both surface dressing and paving materials, the effects on bitumens and tars of several different polymers have been studied in a range of concentrations.

Some of the polymer/binder systems investigated were developed and supplied by commercial organisations; these included tars modified with polyvinyl chloride (PVC), polymethylmethacrylate (PMMA) and nitrile rubber, and bitumens modified with a synthetic rubber cross-linked in situ and styrene-butadiene-styrene block copolymers (SBS).

In addition to these, bitumens containing natural rubber, polyolefins and several ethylene-vinyl acetate copolymers (EVA) were formulated at TRRL.

6.2 Effects on rheological properties of binders

Nearly all the polymers investigated had some effect on the rheological properties of bitumen or tar. As expected some polymers merely stiffened the binder at all temperatures whereas others, such as the synthetic rubber cross-linked in situ and the styrene-butadiene-styrene block copolymer, transformed bitumen into an extremely rubbery binder. Improvements in the properties of bitumens obtained by the addition of polymers belonging to two of the types listed in Section 6.1 will be discussed in more detail after the methods by which these improvements were measured have been described.

6.2.1 Methods of measurement. Measurements of penetration, softening point (R&B), viscosity, creep compliance and dynamic modulus were made on both conventional and modified binders.

It was impossible to characterise the modified binders having extremely non-Newtonian properties by tests commonly applied to conventional binders, such as penetration, softening point and viscosity. Creep tests using a sliding-plate rheometer[4] modified to measure elastic recovery and dynamic tests using a balance rheometer[5] were used more successfully in this respect. One parameter, called here apparent viscosity, was found to correlate closely with the resistance to permanent deformation of rolled asphalt measured in the Wheel-tracking Test. This correlation is discussed in more detail in Section 6.3.

Apparent viscosity was measured using the sliding-plate rheometer in which a sample of binder 30 x 20 mm and between 3 and 10 mm thick was sheared between two aluminium plates. Apparent viscosity, η_a, was calculated using the following standard equation for viscosity,

$$\eta_a = \frac{\text{Shear stress}}{\text{Shear rate}}$$

except that the rate of shear is measured at a strain of precisely 1.0, regardless of whether the sample has reached steady-state flow. By not exceeding a strain of 1.0 the problems associated with non-linear visco-elastic behaviour were largely avoided.

As with the viscosities of ordinary bitumens, values of apparent viscosity for all types of thermoplastic binders varied with rate of shear. Consequently, when making comparisons between binders, values of η_a have been quoted at a common shear rate of 0.05 sec^{-1}.

The sliding-plate rheometer was also used to measure creep compliance (J_t) at temperatures between -10 and $+60^oC$ and over a range of loading times from 3 seconds upwards. Values of J_t could not be measured directly at shorter loading times but they could be calculated using a method of reduced variables[6].

Measurements of properties such as complex modulus and phase angle were made at shorter loading times (down to approximately 0.008 seconds) and at small strains using the balance rheometer. The results from these tests, together with values of creep compliance, are being used to try to establish relationships between these properties and the dynamic properties of bituminous paving materials.

6.2.2 Ethylene-vinyl acetate copolymers. The composition, structure and molecular weight of EVA copolymers can be varied during manufacture and a wide range of these is available commercially, costing at present approximately 7 times as much as bitumen. Initially, 6 of these copolymers containing various proportions of vinyl acetate were mixed in quantities of between 2 and 5 per cent by weight with bitumen. Mixing was easy and with most of these copolymers the temperature susceptibility of the rheological properties of the bitumen was reduced in the range 0 to 60^oC; one copolymer containing 18 per cent vinyl acetate and with a molecular weight of around 16000 was particularly effective. The effectiveness of EVA was not restricted to any one proprietary bitumen and it does not degrade too rapidly at asphalt mixing temperatures. Furthermore, from the price of the EVA itself and the ease with which it could be mixed with bitumen, it appeared that the cost of using EVA was likely to be lower than that of using most of the other polymers investigated, which were in any case less effective. These early results indicated that EVA was the most promising polymer of those investigated in relation to satisfying the requirements of Section 4.

Further research, in which the effects of two more EVA copolymers were also measured, confirmed this view and some of the properties of bitumen modified with the EVA containing 18 per cent vinyl acetate and having a molecular weight of around 16000, are given in Tables 1 and 2; Figures 1 and 2 show apparent viscosity and creep compliance plotted against temperature and loading time respectively. When comparing binders, the most important features of these figures are the slopes of the lines rather than absolute values of viscosity or compliance, because the latter can be adjusted to some extent by changing the hardness of the base binder.

The effects of the addition of EVA on the properties of bitumen can be summarised as follows:—

a) Apparent viscosity and creep compliance became less sensitive to changes in temperature and loading time, respectively. Dynamic moduli were similarly affected.

b) Resistance to deformation or flow is increased at all but low road temperatures and very short loading times.

c) EVA does not confer rubbery characteristics that enable large strains to be accommodated, but it does increase the elastic component of an imposed strain. Measurements of this using the sliding plate rheometer were as high as 60 per cent of a strain of 1.0 at 20°C.

d) Penetration at 25°C and ring and ball softening point are also changed by EVA, and these parameters do give a reasonable guide to the behaviour of EVA bitumen blends in asphalt.

e) EVA does not make the bitumen too viscous at the temperatures used for mixing and laying rolled asphalt. In Table 1, 2 poise and 50 poise were the viscosities chosen as suitable for mixing and compaction, respectively.

f) When subjected to the rolling thin film oven test (RTFOT) bitumens containing EVA hardened by amounts equal to or less than that of the unmodified binder. These results, shown in Table 1, suggest that EVA should not cause any unacceptable changes in rheological properties during the mixing and laying of asphalt.

6.2.3 Elastomers. The effects of elastomers deserve special comment. Natural rubber has been used for many years in bitumen to increase resilience and the ability of the bitumen to undergo large strains without rupture. In the present work it was found that some synthetic rubbers were both more effective in this respect and less susceptible than natural rubber to thermal degradation at asphalt mixing temperatures; styrene-butadiene-styrene (SBS) block copolymers are examples. The properties of bitumens modified with these thermoplastic rubbers have been reported by others[7].

In the present work it was found that, while elastomers such as these reduced dramatically the susceptibility of the rheological properties of bitumen to changes in temperature and loading time and increased apparent viscosity at high road temperatures, they also tended to reduce the modulus of the binder at most road temperatures except at long loading times or large strains. This is what is expected from polymers of this kind and these properties could be valuable for special applications that require high flexibility. Results for bitumen modified with SBS are illustrated in Figures 1 and 2 and these show clearly the properties described above. Although there is some scope for reducing the compliance or increasing the modulus of this binder by blending the polymer with a harder grade of bitumen, the scope is limited if the binder is to remain workable at temperatures at which it will not degrade. The effects of a stiffer binder of this type on the properties of asphalt are discussed later.

6.3 Effects on engineering properties of rolled asphalt

6.3.1 Resistance to permanent deformation. The TRRL Wheel-tracking Test[8] was used to measure resistance to permanent deformation. This test is known to correlate well with the performance of conventional rolled-asphalt wearing courses on straight sections of carriageway[3,9]. It has been established that wearing courses with wheel-tracking rates of 2.0 mm per hour or less are required to cope with the highest levels of commercial traffic[3]. However, for sites where vehicles brake or turn even better wearing courses may be required, because these manoeuvres impose shear stresses that are of the same order of magnitude as the vertical loading.

It was realised in the present work that the relationship already established between tracking rate and road performance for conventional asphalts may not hold for asphalts containing additives that change the visco-elastic properties of the binder substantially. Also, wheel-tracking rate could not be measured accurately enough to differentiate reliably between asphalts with extremely high resistances to deformation. Nevertheless the Wheel-tracking Test offered the best method of assessing the effects of additives on resistance to permanent deformation prior to conducting road experiments.

The improvements in the properties of bitumen resulting from the addition of EVA were reflected clearly in the resistance to permanent deformation of rolled asphalt measured in the Wheel-tracking Test, as the results in Table 2 show. The tests were made on wearing course mixtures containing 30 per cent of coarse aggregate and different binder contents. The optimum binder content of 7.9 per cent, determined in accordance with Section 3 of BS 594: 1973, agreed well with that obtained from the tracking tests. It was interesting to note, however, that the increase in Marshall stability caused by EVA (up to 20 per cent) was small compared with its effect on tracking rate, which was not only reduced but made less sensitive to binder content. Five per cent of EVA by weight of bitumen was more than sufficient to equal or improve on the deformation resistance achieved with heavy duty bitumen having the highest softening point permitted for rolled asphalt wearing courses[10].

The tracking rates obtained using two bitumens modified with SBS copolymers are also included in Table 2, as examples of the effects of very rubbery binders. The properties of the softer of these two binders are illustrated in Figures 1 and 2. Asphalts made with such binders are not only extremely flexible but have quite low tracking rates at 45°C. If, however, apparent viscosity is an accurate guide to resistance to permanent deformation at all temperatures, then the tracking rate obtained with these binders should not decrease as sharply with falling temperature as the tracking rates obtained using conventional, oxidised or EVA binders; tracking tests at 30°C have tended to confirm this. Although the resilience of binders containing elastomers must contribute to resistance to permanent deformation, it cannot be assumed automatically that a low tracking rate at 45°C is a reliable indicator of road performance when the effects of temperature on this property are so obviously different from normal.

Further research is necessary to check the relationship between the wheel-tracking test and road performance for binders with unusual properties, particularly those with properties similar to the bitumen/ SBS blends. This research will, however, be assisted by the ability to predict tracking rate from the properties of the binder as described in the next section.

6.3.2 Relationship between permanent deformation and binder properties. Research by others[3,9] has already shown that the tracking rate of rolled asphalt at 45°C correlates well with the softening point of the binder for a range of binders including both conventional and heavy duty bitumens.

Although for some modified binders, including those containing EVA, softening point did provide a reasonable guide to performance in the Wheel-tracking Test, it could not be used reliably for all binders; those with highly visco-elastic properties such as bitumens containing SBS were most notable in this respect as the results in Table 2 show.

The complete characterisation of all the modified binders investigated could only be achieved by determining a wide range of visco-elastic functions, but a comprehensive knowledge of these was not necessary in order to predict tracking rates. Figure 3 shows that apparent viscosity at a shear rate of 0.05 $secs^{-1}$ and 45°C, which can be measured quickly and simply, was found to correlate extremely well with tracking rate at 45°C for all the binders studied so far. The correlation coefficient determined using a simple regression analysis was 0.98.

6.3.3 Dynamic modulus. These measurements were made in flexure on asphalt beams approximately 375 x 100 x 50 mm using sinusoidal loading patterns. The complex modulus and compliance and their storage and loss components were determined at various temperatures between –11 and +43°C, over a frequency range from 0.1 to 80 Hz.

A method of reduced variables[6] was used to determine the relationship between the effects of temperature and loading time (test frequency) on these viscoelastic functions; this enabled them to be plotted over a wide range of frequency at any temperature between –11° and +43°C.

The complex moduli of rolled asphalts made with various binders have been reduced to a reference temperature of 33°C and plotted against test frequency in Figure 4. The results obtained for a sulphur-asphalt, described elsewhere[1] in more detail, together with those obtained for an asphalt modified with the epoxy-resin-based binder referred to in Section 5, have been included in Figure 4 for the purposes of making comparisons.

The important features of the asphalts compared in Figure 4 can be summarised as follows:–

a) The modulus of the asphalt modified with epoxy resin was much greater than that of the conventional asphalt at all test temperatures and frequencies; at 33°C and 5 Hz the epoxy asphalt was 10 times stiffer than the control asphalt.

b) The modulus of the sulphur asphalt was also greater than that of the control asphalt at all test temperatures and frequencies; at 33°C and 5 Hz the sulphur asphalt was approximately 2.5 times stiffer than the control asphalt.

c) At 33°C the modulus of the asphalt containing EVA was approximately 2.5 times greater than that of the control asphalt at test frequencies relevant to road conditions. At much higher frequencies (or low road temperatures) the moduli of the EVA and control asphalts were similar.

d) The moduli of the asphalts modified with epoxy resin, EVA and sulphur increased relative to that of the conventional asphalt as the test frequency decreased. This suggested that increasing the test temperature would have a similar effect. Measurements above 33°C confirmed this and these trends have been quantified in terms of the shift factors calculated from the reduced variables method.

e) The modulus of asphalt modified with SBS was lower than that of the control asphalt at all test temperatures and frequencies.

f) At 33°C the composite curves representing the moduli of the asphalts containing conventional and heavy duty bitumens cross at a test frequency of about 2 Hz, with the modulus of the heavy duty asphalt increasing slightly relative to the control asphalt towards the lower test frequencies (and higher temperatures).

The increases in modulus achieved by the addition of sulphur, epoxy resin and EVA were particularly interesting because improvements of this kind could also be valuable in roadbase and basecourse materials. The effect of EVA was particularly notable because the increase in stiffness was concentrated at the higher temperatures.

Another important aspect of the dynamic tests concerned resistance to permanent deformation. The ability to predict this from dynamic measurements would be extremely valuable, particularly for mixtures that contain large aggregates and cannot be tested reliably in the Wheel-tracking Test. Modulus obviously has a strong influence on permanent deformation because, for an unconstrained material, it determines the total strain resulting from an applied stress. The visco-elastic characteristics of the material are also important because these will determine the proportion of the total strain that is non-recoverable. Research is in progress to establish a relationship between some function representing non-recoverable strain, derived from the dynamic measurements made at temperatures and loading times corresponding to road conditions, and permanent deformation measured on the road or in wheel-tracking tests.

6.3.4 Fatigue-life. Under normal road conditions, rolled-asphalt wearing courses are very resistant to cracking. Consequently, there is a paucity of evidence for its failure by fatigue, and an authoritative correlation between laboratory fatigue behaviour and road performance has yet to be established.

Nevertheless, measurements of laboratory fatigue life were useful. By using the results obtained with conventional asphalt as a reference, comparisons were made that gave a guide to the effects of additives on this property.

Measurements of complex modulus and fatigue life were made on 225 x 50 x 50 mm samples loaded in uniaxial alternating compression and tension at a constant temperature of 25°C over a range of stress amplitudes[11]. The stress amplitude was kept constant throughout each test and in every case the test frequency was 25 Hz. Measurements of this kind have been made on asphalts containing conventional and heavy duty bitumens and those containing EVA, SBS and sulphur additives.

The complex moduli measured in this uniaxial test agreed well with those measured in the flexural test and shown in Figure 4.

The characteristic curves of initial strain versus fatigue life in terms of number of load cycles to failure are plotted in Figure 5. These show that the different binders did give rise to small differences in fatigue behaviour but because of the scatter in the results, which is inevitable in measurements of this kind, the differences between the conventional asphalt and those made with the heavy duty and EVA binders were not statistically significant. However, the differences between the conventional asphalt and those containing sulphur and SBS, which decreased and increased fatigue life respectively, were significant.

The pattern of fatigue behaviour illustrated in Figure 5 is, of course, changed when stiffness is taken into account. If the fatigue lives of the various asphalts are compared at a common level of stress instead of a common level of initial strain, the stiffer materials (those containing EVA and sulphur) are better than the conventional asphalt. Such characteristics would be valuable if reproduced in roadbase and basecourse materials because, under road conditions, strains in the pavement would be reduced with a consequent improvement in their fatigue behaviour.

7. FULL-SCALE MIXING AND LAYING

Following the laboratory work that has been described, full-scale mixing and laying experiments were carried out. The principal objectives of these experiments were to determine the effects of EVA and sulphur on the mixing and laying characteristics of rolled asphalt and to determine whether the improvements obtained with these additives in the laboratory could be reproduced on a bulk scale. The results obtained with sulphur have already been reported[2].

A total of 140 tonnes of asphalt modified with 5 per cent of EVA (18 per cent vinyl acetate and molecular weight 16000) and 50 tonnes of asphalt containing a conventional 50 pen bitumen, were mixed and laid within the precincts of the contractor's quarry area. Details of these asphalts, which were designed using the procedure in BS 594, are given in Table 3. Precoated Craig-yr-Hesg chippings (20 mm) were applied to all the asphalts to provide surface texture. Rates of spread of these chippings were not measured during laying, but were estimated subsequently by counting chippings over several square metres of the surface.

The control asphalt was mixed at around 180°C and compacted to a thickness of about 50 mm, with the temperature at the centre of the asphalt carpet being between 140 and 150°C at the start of rolling. The contractor had considerable experience of mixing and laying asphalt of this composition and advised that these temperatures would allow good compaction to be obtained with sufficient embedment of the precoated chippings.

A further 70 tonnes of asphalt containing the 70 pen bitumen modified with EVA were then mixed, again at a temperature of around 180°C. Attempts to roll this asphalt at 140°C, however, failed because it was too mobile to be compacted properly and the precoated chippings were pushed beneath the surface. This accounted for the rather low estimated rate of spread of chippings at this rolling temperature given in Table 3. Further loads of the modified asphalt were allowed to cool to between 90 and 100°C before rolling, and at these temperatures the asphalt displayed good handling characteristics.

To explore these changes in mixing and laying characteristics more fully, the remainder of the asphalt containing EVA was mixed at 140°C and compacted at temperatures between 70 and 100°C. Only when the temperature fell below about 80°C was there difficulty in obtaining sufficient embedment of the precoated chippings. It is clear that the workability of asphalt modified with EVA is much greater than expected on the basis of the binder viscosities given in Table 1, but a satisfactory explanation of this has yet to be established. However, this evidence indicated that blends of EVA with a harder grade of bitumen would be a particularly promising option for future investigation.

Laboratory tests on samples of asphalt taken from the laid surfacings have shown that resistance to permanent deformation was improved by a factor of between 2 and 6. The use of different mixing and rolling temperatures appears to be at least partly responsible for the variable degree of improvement although the number of tests made was insufficient to be able to draw firm conclusions given the inevitable variability found in testing small samples of asphalt.

Overall, the results from the full-scale experiments are extremely promising and justify further experiments with EVA in rolled asphalt so that its performance can be determined under heavily trafficked conditions and compared with that of other mixes of high stability.

8. CONCLUSIONS

1. Laboratory experiments have shown that polymers can be used to improve the properties of binders and, therefore, rolled asphalt wearing courses, in a variety of ways including increasing resistance to permanent deformation and dynamic stiffness.

2. A copolymer of ethylene and vinyl acetate (EVA) was the most promising in improving resistance to permanent deformation and modulus without adversely affecting laboratory fatigue life.

3. The results of laboratory experiments with other polymers such as epoxy resins and elastomers were also promising and will form the basis of further work in connection with improved surfacings for bridge decks and for overlaying joints in concrete roads.

4. The resistance to permanent deformation of rolled asphalts (including those containing modified binders) measured in the TRRL Wheel-tracking Test, can be predicted from the apparent viscosity of the binder measured in a simple creep test.

5. Full-scale mixing experiments confirmed the improvements in resistance to permanent deformation found with EVA in laboratory experiments and showed that EVA also improved the workability of rolled asphalt, allowing it to be mixed and laid at lower than normal temperatures. A road experiment should, therefore, be carried out to establish that these improvements are reflected in better road performance.

6. The improvements gained from adding EVA to rolled-asphalt wearing course mixtures and in particular the increase in modulus effected at high temperatures, could be valuable in roadbase and basecourse materials. Research to investigate this is in progress.

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10. REFERENCES

1. DENNING, J H and J CARSWELL. The use of sulphur to reduce the permanent deformation of asphalt mixes. *Proceedings of 'Colloque internationale sur l'utilisation des sous-produits et déchets dans le genie civil'.* Paris, November, 1978.

2. DENNING, J H and J CARSWELL. Improvements in rolled-asphalt surfacings by the addition of sulphur. *Department of the Environment Department of Transport, TRRL Report* LR 963. Crowthorne, 1981 (Transport and Road Research Laboratory).

3. SZATKOWSKI, W S. Rolled asphalt wearing courses with high resistance to permanent deformation. Conference on the performance of rolled asphalt road surfacings, Institution of Civil Engineers. London, 1979.

4. FENIJN, J and R C KROOSHOF. The sliding-plate rheometer. A simple instrument for measuring the viscoelastic behaviour of bitumens and related substances in absolute units. *Proceedings of CTAA.* Winnipeg, Canada, November 1970.

5. YAMAMOTO, M. Theoretical analysis of new rheometers. *Japanese Journal of Applied Physics,* 1969, 8, (10).

6. FERRY, J D. Dependence of viscoelastic behaviour on temperature. *Viscoelastic properties of polymers.* New York, 1961 (John Wiley and Sons), pp 201–247.

7. VAN BEEM, E G and P BRASSER. Bituminous binders of improved quality containing 'Cariflex' thermoplastic rubbers. *J Inst Petroleum* 1973, 59 (566).

8. ROAD RESEARCH LABORATORY. The wheel-tracking test. *RRL Leaflet* 50. Crowthorne, 1971 (Road Research Laboratory).

9. SZATKOWSKI, W S and F A JACOBS. Dense wearing courses in Britain with high resistance to deformation. *Paper to Symposium on deformability of bituminous surfacings.* ETH, Zurich, 1977.

10. DEPARTMENT OF TRANSPORT. Specification for road and bridge works, rolled asphalt wearing courses. *Departmental Standard* HD/2/79. London, 1979 (H M Stationery Office).

11. GODDARD, R T N, W D POWELL and M W APPLEGATE. Fatigue resistance of dense bitumen macadam: the effect of mixture variables and temperature. *Department of the Environment Department of Transport, TRRL Report* SR 410. Crowthorne, 1978 (Transport and Road Research Laboratory).

TABLE 1

Effect of EVA on the properties of bitumen

Binder	Pen 25°C	R&B °C	Temperature °C		After RTFOT*	
			For viscosity of 2 poise	For viscosity of 50 poise	Pen 25°C	R&B °C
Conventional bitumen (A)	56	52	174	112	37	61
(94% A + 6% 300 pen) + 5% EVA	42	68	184	115	33	74
(78% A + 22% 300 pen) + 5% EVA	51	63	178	109	38	70
A + 2% EVA	52	60	181	117	32	68
A + 3.5% EVA	41	64	186	116	29	71
A + 5% EVA	35	70	195	120	26	78

* Rolling Thin Film Oven Test. ASTM Standard No. D2872–70.

TABLE 2

Properties of binders and wheel-tracking rates of rolled-asphalt wearing courses

Binder	Description	Pen 25°C	R&B °C	Apparent viscosity at shear rate 0.05 $secs^{-1}$ 10°C	45°C	Wheel-tracking rate at 45°C mm/hour
A	Conventional bitumen	56	52	1.2×10^8	7.5×10^4	3.2
B	A + 2% EVA	52	60	1.5×10^8	4.1×10^5	1.2
C	A + 2.5% EVA	46	63	1.0×10^8	3.0×10^5	–
D	A + 3.5% EVA	41	64	8.0×10^7	5.0×10^5	0.9
E	A + 5% EVA	35	70	8.0×10^7	1.3×10^6	0.4
F	(94% A + 6% 300 pen) + 5% EVA	42	68	6.4×10^7	7.2×10^5	0.7
G	Bitumen/SBS	158	80	1.8×10^6	1.8×10^5	2.8
H	Bitumen/SBS	84	90	1.9×10^7	7.7×10^5	0.7
I	100 pen grade bitumen + 5% Natural rubber	84	53	2.0×10^7	5.0×10^4	3.4
J	100 pen grade bitumen	92	46	3.4×10^7	1.7×10^4	9.0
K	200 pen grade bitumen	202	38	8.0×10^6	3.9×10^3	23
L	35 pen grade bitumen	33	59	5.6×10^8	3.2×10^5	1.4
M	Heavy duty bitumen	49	59	1.2×10^8	3.7×10^5	1.2
N	Heavy duty bitumen	42	68	1.5×10^8	8.1×10^6	0.7
O	Oxidised bitumen	44	78	8.5×10^7	2.1×10^6	0.6

TABLE 3

Asphalts used in full-scale mixing experiments

Binder				Asphalt									
Type	Pen 25°C	R&B °C	η_a at 45°C (poise)	Composition: designed to Section 3 of BS 594			Quantity (tonnes)	Mixing temperature °C	Compaction temperature °C	Max rate of spread of precoated chippings kg/m^2	Density gm/cc	Tracking rate mm/hour
				Coarse aggregate	Sand	Binder content						
Bitumen	48	55	9.0×10^4	30% Limestone (quarry, Chipping Sodbury)	Hilton pit (Bridgenorth)	7.5%	50	180	140–150	8.5	2.254	2.6
Bitumen* plus 5% EVA	52	64	3.5×10^5				80	180	140–150	7	2.320	0.4
									90–100	12	2.281	0.4
							60	140	90–100	10.5	2.298	1.5
									70–80	13	2.262	0.8

* Penetration at 25°C, 67. Softening point (R&B) 51°C.

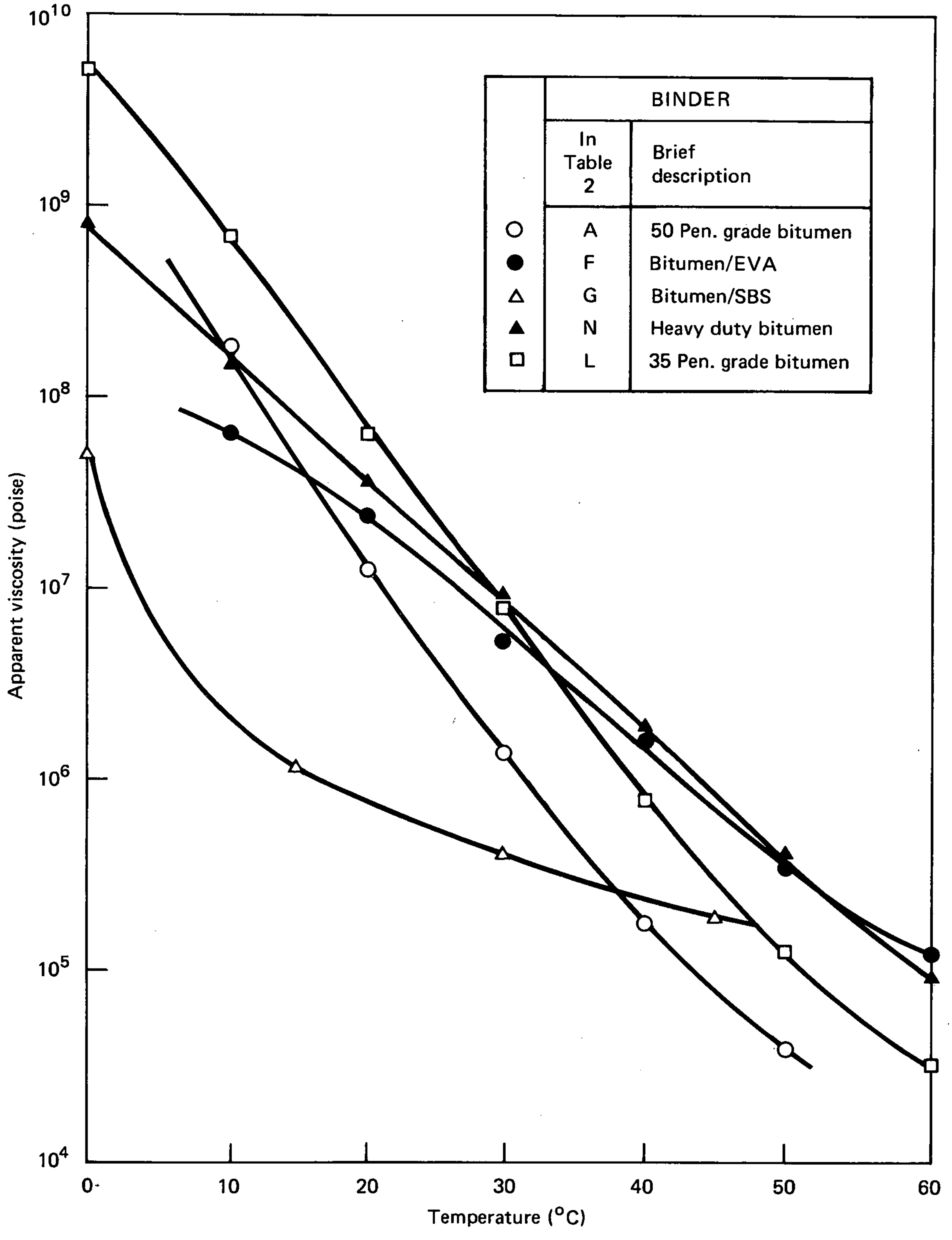

Fig.1 Relationship between temperature and apparent viscosity of binders

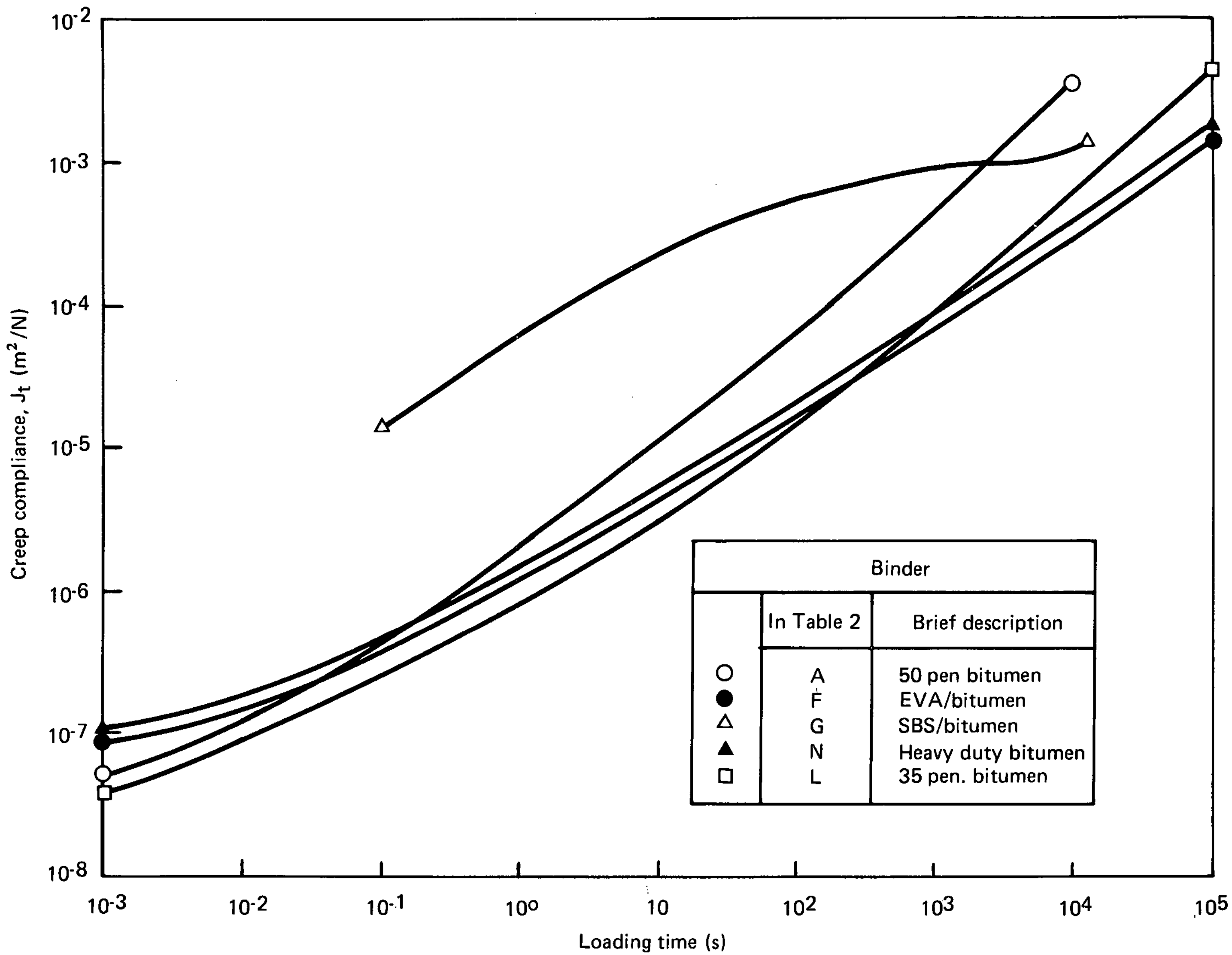

Fig. 2 Composite curves of creep compliance reduced to 20°C

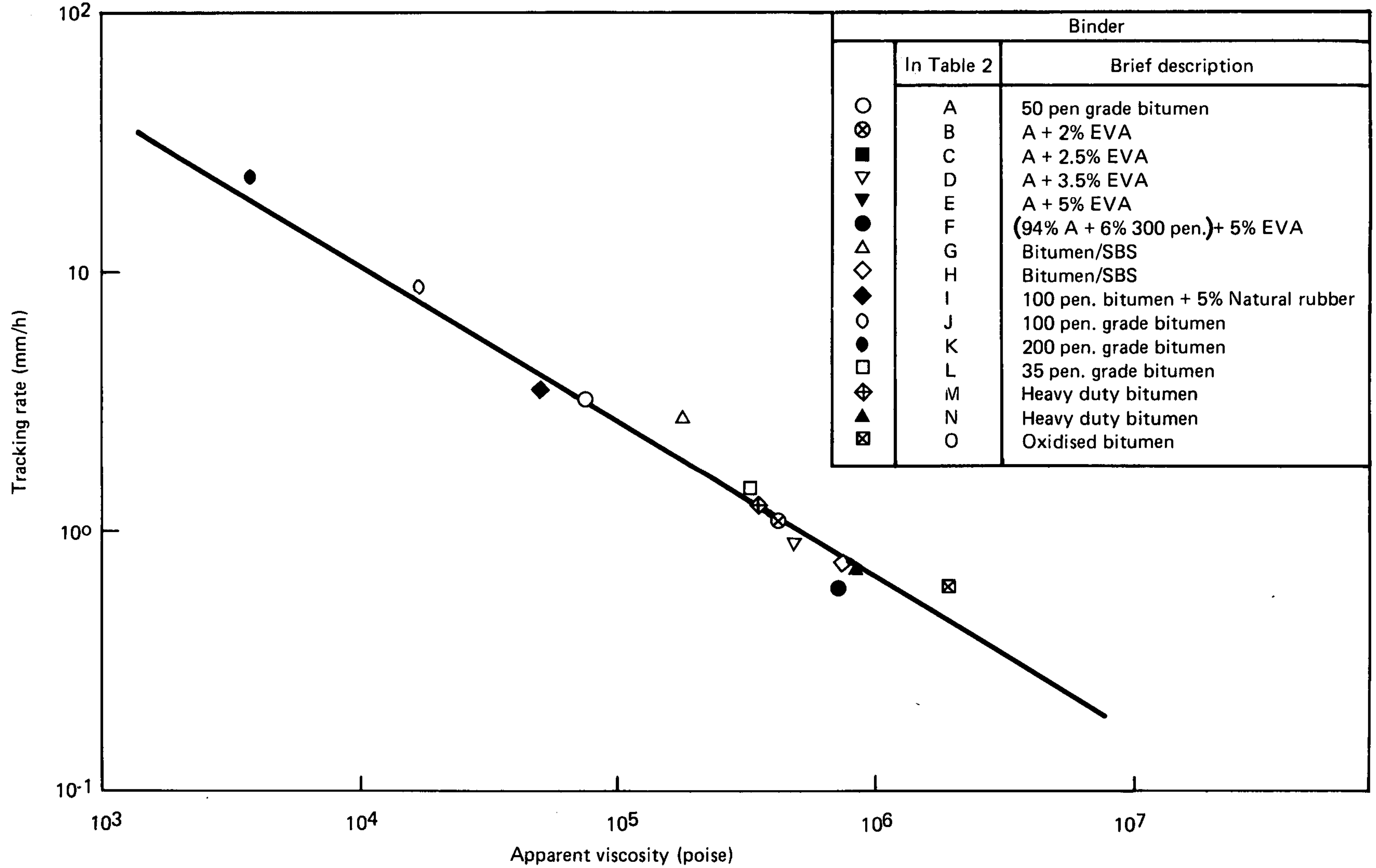

Fig. 3 Relationship between the wheel-tracking rate of rolled asphalt containing 30 per cent coarse aggregate and the apparent viscosity of the binder, at 45°C

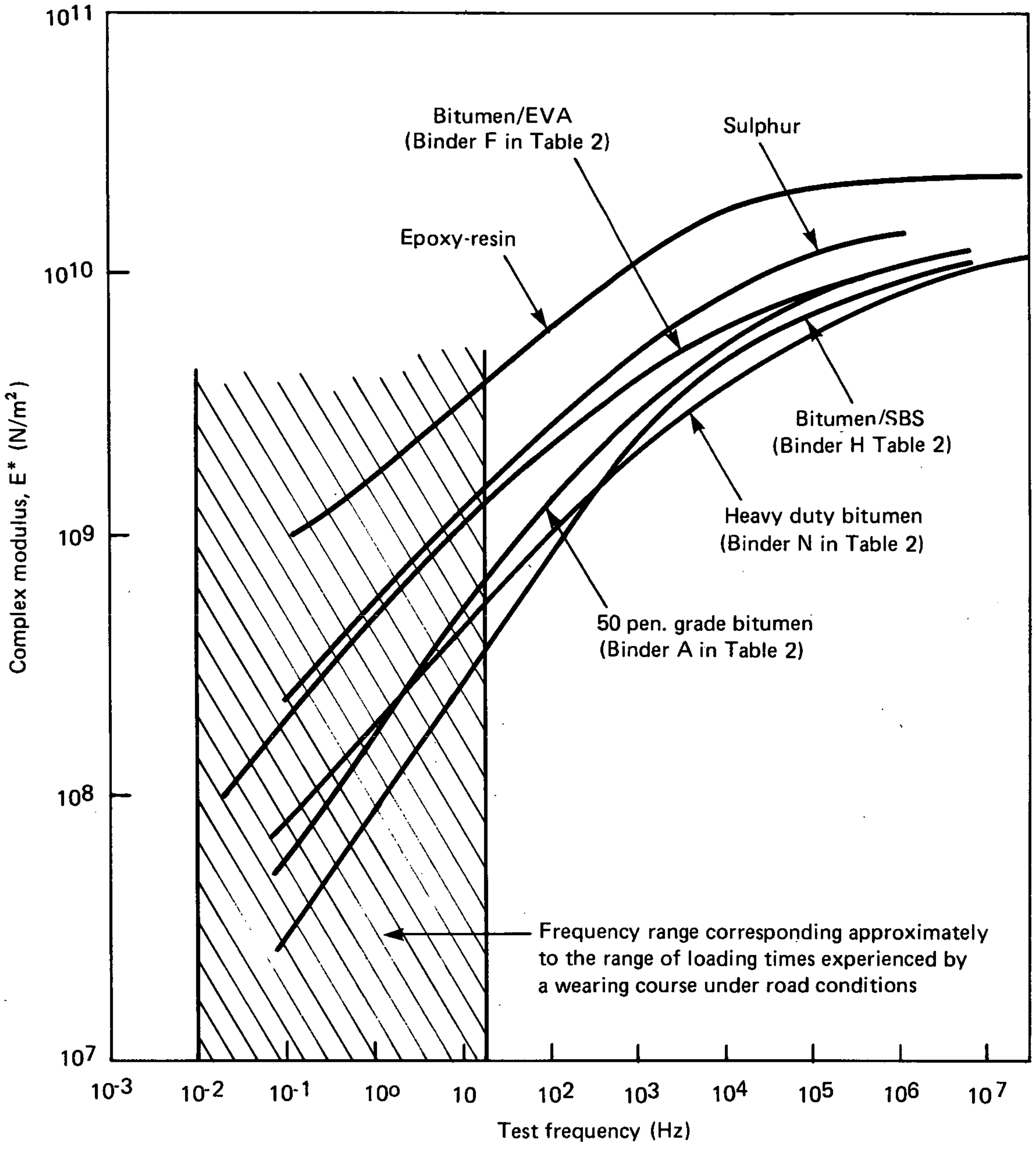

Fig. 4 Composite curves of complex modulus for rolled-asphalt wearing courses containing different binders, reduced to 33°C

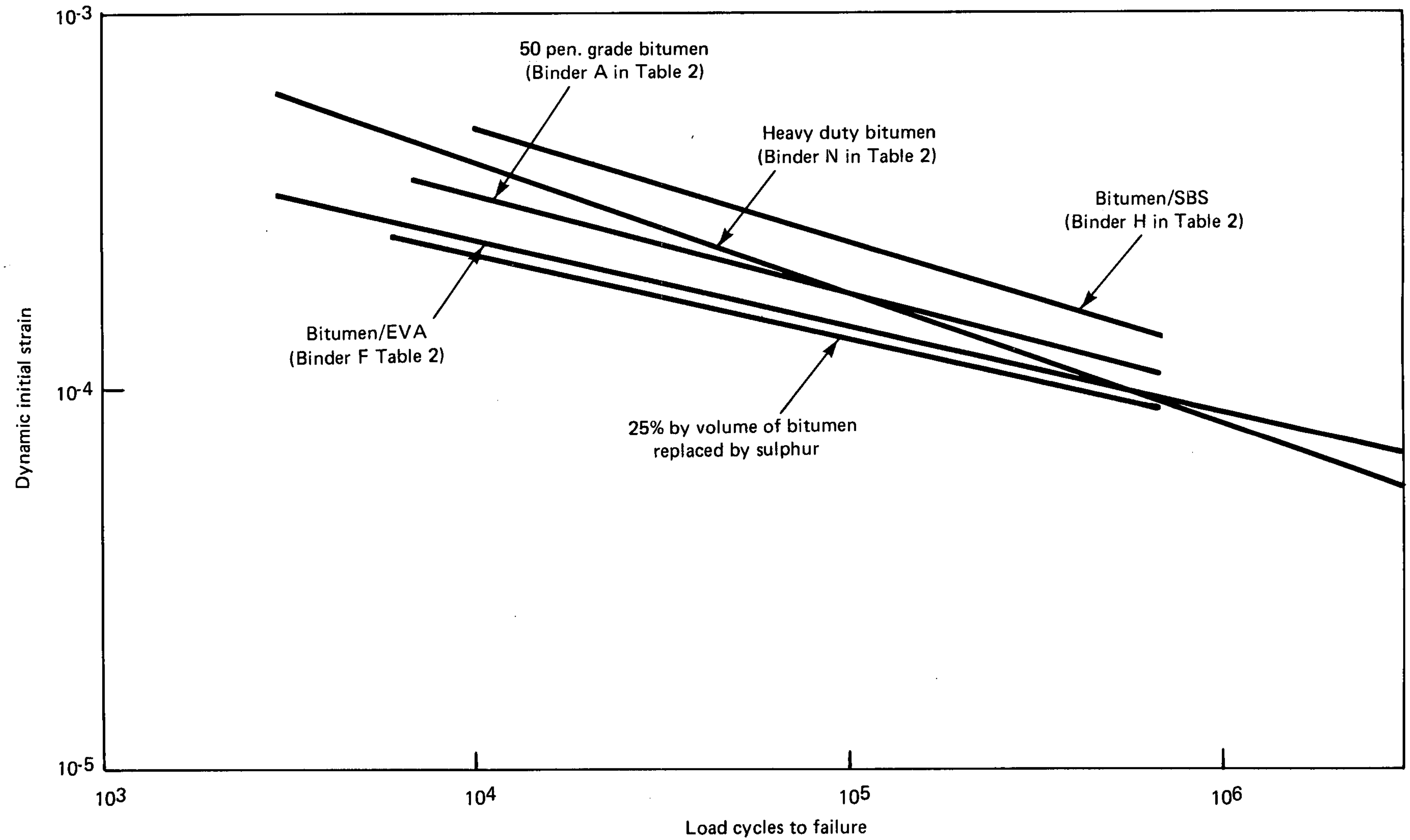

Fig. 5 Relationship between laboratory fatigue life and dynamic initial strain for rolled-asphalt containing different binders

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ABSTRACT

Improvements in rolled asphalt surfacings by the addition of organic polymers:
J H DENNING BSc PhD C Chem MRSC and J CARSWELL BSc: Department of the Environment Department of Transport, TRRL Laboratory Report 989: Crowthorne, 1981 (Transport and Road Research Laboratory). The report discusses the use of various organic polymers to improve the properties of bituminous binders, and describes the effects of these improvements on the resistance to permanent deformation, dynamic stiffness and laboratory fatigue life of rolled asphalt wearing courses.

Emphasis has been placed on improving resistance to permanent deformation to meet the demand for better surfacing materials for very heavily trafficked roads. Of the materials investigated so far, a copolymer of ethylene and vinyl acetate (EVA) was found to be the most effective and simplest to use. Binders containing EVA also improved the dynamic stiffness of rolled asphalt without adversely affecting laboratory fatigue behaviour. Workability during mixing and laying was also improved.

Measurements of the effects of EVA and other polymers, such as epoxy resins and elastomers, on the structural properties of rolled asphalt, and the correlation of some of these properties with those of the binder, have also provided a basis for assessing the potential benefits of using these polymers in other types of bituminous material.

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