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A DENSE COATED ROADBASE MACADAM OF IMPROVED PERFORMANCE

by

D Leech

Pavement Design Division
Highways Department
Transport and Road Research Laboratory
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ABSTRACT

An assessment has been made of the effects of binder hardness and filler content on the performance of dense coated roadbase macadams containing 40 mm crushed granite aggregate and limestone filler with either bitumen or tar binder. The materials were laid and compacted using full-scale plant; they included 50 and 100 penetration bitumen, 54 and 58 evt low temperature tars and filler contents in the range 3 to 11 per cent. Samples were cut from the laid materials to measure deformation resistance, dynamic stiffness and resistance to fatigue. Corroborative work with other crushed aggregates provided more data on dynamic stiffness and reassurance concerning possible mixing problems.

Binder contents within the present specification range are sufficient to coat most aggregates containing up to 10 per cent filler and dense roadbase macadam with the binders of higher viscosity and about 8 per cent filler confers significant benefits through better load spreading and deformation resistance. Furthermore, at equiviscous temperatures of rolling, the material was shown to be as easy to compact as conventional dense coated macadam. In heavily trafficked roads, its use would allow significant reductions of design thickness or, alternatively, a marked extension of pavement life.

1. INTRODUCTION

The dense coated macadam used in the construction of flexible roads consists of a continuously graded aggregate mixed with a bitumen or tar binder: a British Standard Specification defines the composition[1]. Although the performance of materials to this specification is generally satisfactory, the need for a bituminous roadbase material of improved performance has been highlighted recently by the reconstruction of heavily trafficked roads. The inevitable traffic delays associated with reconstruction of the roadbase and surfacing may be minimised by the use of bituminous materials because there are few restrictions on site traffic and there is no need to allow for a curing period; in contrast to concrete construction, once a dense coated macadam has cooled to ambient temperature after laying it can be trafficked. However, the available construction depth is usually restricted by clearances under bridges, and by the need to maintain drainage levels. As a result it is often impossible to accommodate the greater thicknesses of conventional coated macadam required to carry the much heavier traffic for which reconstructed pavements must be designed. If pavements are to be reconstructed in the available depth and as rapidly as possible, a bituminous roadbase material of superior performance is required. Such a material would also have advantages as a roadbase and basecourse in new construction.

In 1978 a joint programme of research was initiated by the Transport and Road Research Laboratory, the Asphalt and Coated Macadam Association, the British Tar Industry Association and the Refined Bitumen Association. It set out to investigate the possibility of improving the performance of roadbase and basecourse coated macadams. In particular, the aim was to study the performance of well compacted macadams containing more filler and a harder binder than normal. The materials have the main features of grave-bitume, a French roadbase material that may have a performance better than that of dense bitumen macadam[2,3].

The existing British Standard Specification[1] for roadbase and basecourse macadam does not permit the use of bitumen as hard as 50 penetration although this binder is widely used in hot rolled asphalt and compares with the 40/50 grade bitumen used in grave-bitume. The effect of reducing the bitumen penetration from 100 to 50 was therefore studied in the present work. The binders chosen for the tarmacadam materials were 54 evt and 58 evt low temperature tars. 54 evt tar is commonly used in roadbase and basecourse macadams while 58 evt tar is used only in materials containing flint gravel aggregate. The range of filler content investigated was from three per cent, a value frequently found in practice in dense coated macadams, to thirteen per cent; the middle of this range, eight per cent, is the maximum presently permitted for roadbase macadam, but typical of grave-bitume. Pilot-scale studies were made to determine the effect of filler content and binder hardness on compactability of both bitumen macadams and tarmacadams containing granite aggregate: performance properties of the compacted materials were assessed by measurements of dynamic stiffness modulus, resistance to deformation and fatigue cracking. Work on the same type of materials but containing different aggregates is also reported.

2. PILOT SCALE COMPACTION TRIALS

Because the performance properties of bituminous materials are largely dependent on their level of compaction it is essential when developing new materials to study their compactability at an early stage.

Continuously graded Bardon Hill granite aggregate of 40 mm nominal size was mixed with limestone filler and the appropriate binder at a commercial plant. Conventional roadbase macadams with 100 pen bitumen and 54 evt tar were prepared as control materials. The test materials contained aggregate of similar grading but with more filler and with either 50 pen bitumen, 54 evt tar or 58 evt tar. To study the effect of binder content three materials containing 58 evt tar and high filler content were mixed.

Material containing 100 pen bitumen was mixed at 130–140°C whereas the 50 pen materials were mixed at the corresponding equiviscous temperature of 150–160°C. Mixing temperature for the 54 and 58 evt tar materials were well within the specification ranges of 95–110°C and 105–125°C respectively; again the intention was to achieve equal viscosities.

Pilot-scale compaction trials were carried out on a foundation of realistic stiffness comprising a 100 mm thick crushed granite sub-base on a heavy clay subgrade. The materials were laid to an uncompacted depth of about 180 mm over a total area about 100m by 2.8m using a Blaw Knox PF–90 paver. Each material was divided into two areas, one of which received 25 passes of a 9 tonne tandem deadweight roller, the other 7 or 10 passes. In order to determine the mean rolling temperature, temperatures at mid-depth were taken at one metre intervals. The materials containing 50 pen bitumen were rolled at 110–120°C and the 100 pen material at 85–95°C, close to the equiviscous temperature appropriate for rolling. The rolling temperatures for the materials containing 54 and 58 evt tars were 80–90°C and 85–95°C respectively.

Cores of each material were taken for composition analysis and mean results are given in Table 1. The control materials represent typical roadbase macadam to the present specification[1] except that in the case of the bitumen control there is a small excess, about 4 per cent, of material passing the 3.35 mm sieve. In the case of materials 6 and 7 containing 58 evt tar, the amounts of aggregate passing the 14 mm sieve were excessive even after allowing for the effect of the added filler. The binder contents for materials 4, 5 and 6 are a little less than the lower specification limit of 3.7 per cent but this is compensated by the low specific gravity of the low temperature tars used.

TABLE 1

Composition of materials

	Bitumen materials			Tar materials				
	100 pen	50 pen		54 evt tar		58 evt tar		
	control	low filler	high filler	control	high filler	high filler		
Material identification	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Binder content (per cent by mass)	3.3	3.2	3.7	3.6	3.6	3.5	4.0	4.2
Mean aggregate grading (per cent passing BS sieve (mm))								
37.5	97	100	100	100	100	100	100	100
28	87	92	92	96	96	98	95	90
14	67	66	72	76	82	92	88	83
6.3	55	52	60	55	61	65	62	56
3.35	50	46	52	40	43	52	45	41
0.3	12	13	18	16	18	22	20	18
0.075	3	3	8	5.3	9.5	10.8	9.2	9.3

Previous work[4] has demonstrated that the percentage of voids in the mineral aggregate, VMA, is a useful indicator of the state of compaction. In the present work results of density measurements and composition analyses were used to calculate VMA and Figure 1 shows its variation with roller passes for each of the bitumen macadams. In previous work where a single grading of crushed rock aggregate had been employed, results fell close to a single straight line but, because of differences in grading, the present results lie on three parallel lines. These are brought into coincidence if the results are expressed in terms of Percentage Refusal Density (PRD), the density of each material as a percentage of its density after compaction to an ultimate level in a refusal test[5]. Figure 1 shows that there is a single relationship between PRD and number of roller passes, indicating that the materials are equally compactable when compared in terms of the fundamental compaction parameter, PRD.

It was found that VMA was affected by the amount of filler (passing 75 μm) and fine aggregate (passing 3.35 mm but retained on 75 μm sieve) in the material. Compared with the 100 pen control, the low filler material containing 50 pen bitumen has a lower percentage of fine aggregate and its refusal VMA was found to be lower by just over one per cent. Also the refusal VMA for the high filler material was found to be lower than for the low filler materials. For the particular materials studied and the range of test conditions it was observed that either an increase in filler content or a decrease in fines reduced the VMA at refusal, as shown in Figure 2; this is presumably because either condition results in more efficient packing of the aggregate.

Figure 3 shows the compactability results for the tarmacadams. Compactability was clearly influenced by binder content, the VMA of the two richest materials being reduced to a greater extent by increasing compactive effort. Figure 3 also shows that when level of compaction is expressed in terms of PRD there is a different relation between PRD and roller passes for each of the two levels of binder content. This could be because high levels of compaction are more difficult to achieve at very low levels of binder content[6] and the relatively fine grading of the tarmacadams demanded more tar than was used. In fact the material containing 3.5 per cent by weight of tar and 10.8 per cent filler had barely enough binder to coat the aggregate and the material tended to break up in coring, particularly at the lower level of compaction. Overall, the evidence shows that increasing binder viscosity and filler content has no adverse effect on compactability provided the aggregates are properly coated and mixing and rolling temperatures are adjusted to allow for the different viscosities of the binders used.

It has been demonstrated elsewhere that there is considerable scope for improving compaction and thus performance of conventional roadbase macadams in the UK[6]; if the same typical compactive efforts are applied to these new dense coated macadams containing more viscous binders and higher filler contents the same conclusions can be drawn.

Having established the state of compaction of these materials, beams and slabs were removed from the pilot scale pavements to measure properties that influence performance in the road.

3. DYNAMIC STIFFNESS MODULUS

Any improvement in the load spreading capability of roadbase macadam will reduce the vertical stresses developed beneath the roadbase by traffic and thus reduce the deformation in the sub-base and subgrade; this deformation is often an important part of the total deformation appearing at the pavement surface. The dynamic stiffness modulus of roadbase macadam is a good measure of its ability to reduce the stresses developed in the sub-base and subgrade by traffic loading. Dynamic stiffness will vary according to the temperature of the material and the frequency of the cycle of loading applied by moving traffic. In the UK the critical roadbase temperatures, when the greatest stresses are transmistted to the sub-base and sub-grade and when greatest deformation occurs, are between 20 and 35°C and the duration of the load pulse can usually be represented by a frequency within the range 5 to 10 Hz.

3.1 Pilot-scale trials

Samples of material 37 cm long x 10 cm wide x 6 cm deep were removed from the experimental pavements laid in pilot-scale trials and tested in repeated dynamic three-point bending. Loading frequency was varied over the range 0.1 to 100 Hz and temperature from −10°C to +40°C, ie covering ranges that are relevant to all practical road conditions. In Figures 4 and 5 the value of the stiffness modulus is plotted against frequency at a reference temperature of 10°C for materials that had received 25 roller passes; the visco-elastic nature of the material allows a conversion factor to be derived to calculate the dynamic stiffness at other temperatures as shown in the insets on Figures 4 and 5.

Figure 4 shows the significant increase in stiffness modulus in bitumen macadams associated with a reduction in nominal binder penetration from 100 to 50 pen; under typical road conditions the increase is nearly four-fold. The effect of increasing filler content from 3 to 8 per cent is less marked, the corresponding increase in stiffness being only about 30 per cent.

Figure 5 shows the change in stiffness modulus of tarmacadam associated with an increase of filler content and with an increase of tar viscosity. At realistic frequency and temperature conditions of 5 Hz and 25°C, increasing filler content from 5.3 to 9.5 per cent raises the dynamic stiffness of the material from 2.3 to 4.9 GPa. The use of 58 evt tar appears to raise the dynamic stiffness further to 8.0 GPa, but Figure 6, relating stiffness to the state of compaction, shows that part of this figure is attributable to a higher level of compaction. At 95 PRD, a level of compaction representative of that typically achieved on site, the increase of filler content has doubled the dynamic stiffness whereas the combined effect of more filler and higher viscosity tar is to treble the stiffness. It is of interest to note that the recovered evt values of the two tars indicate viscosities equivalent to those of 50 and 35 pen bitumen at 25°C and, taking into account the effect of compaction, the dynamic stiffness of the tarmacadams and bitumen macadams are in good agreement.

3.2 Further corroborative work

To confirm the increased stiffness of roadbase macadams with harder binder and more filler, further dynamic stiffness tests were carried out on materials containing granite, limestone and blast furnace slag aggregates. The results are summarised in Table 2. Material A was laid in a full-scale pavement test designed to compare the performance under repeated wheel loading of a dense bitumen macadam roadbase with high filler content and harder bitumen with that of a conventional macadam roadbase. Materials B and C had very high filler contents coupled with the use of 50 pen bitumen and were laid to investigate the effect on coating of the aggregate and on dynamic stiffness. Although materials containing 100 pen bitumen were not available for comparison a slag containing 200 pen bitumen was laid. Material D was used in a full-scale motorway trial of the improved roadbase material.

TABLE 2

Summary of dynamic stiffness and composition data for corroborative studies

Material	Binder		Filler	PRD	Dynamic stiffness modulus
	Pen nominal	Per cent by mass	Per cent by mass	Per cent	GPa 25°C 5Hz
(A) Crushed granite	100	3.7	3.5	95.8	0.9
	50	3.5	8.0	97.6	3.3
(B) Crushed limestone	50	2.6	11.0	95.8	1.5
(C) Blast furnace slag	200	5.3	4.3		0.4
(Bulk density	50	5.1	9.4	95†	1.8
1200 kg/m^3)	50	5.5	12.1		2.1
	50	4.7	13.0		2.1
(D) Limestone	100	3.7	7.2	95†	1.1
	50	3.9	7.8		1.5

† estimated from observations of the rolling

For materials to the present specification containing 100 pen bitumen and compacted to the same degree as the materials in Table 2, the predicted dynamic stiffness modulus is close to 1.0 GPa at 25°C and 5 Hz[7]. Comparison with the results given in Table 2 and those from the pilot-scale trials, indicates that the stiffness of the improved macadam is 1.4 to 3.5 times that of a conventional macadam; this improvement is achieved by increasing the bitumen hardness from 100 to 50 pen (or 54 to 58 evt tar) and doubling the filler content. Much of the variation in the increase in stiffness achieved may perhaps be attributed to the variation in viscosity of the binder within the specification range.

The practicality of laying materials with high filler content was confirmed by the tests on materials B and C. The target binder content[1] was 4.8 per cent but the supplier of the blast furnace slag normally sets a target of 5.2 per cent to ensure that the slag is sufficiently well coated. The material containing 4.7 per cent bitumen and 13 per cent slag filler was mixed by combining the aggregate and filler before adding the bitumen, thus allowing the filler to mix with the bitumen before undue loss of bitumen had occurred into the pores of the aggregate. With filler contents of 11 and 13 per cent in materials B and C the aggregates were barely coated with bitumen and yet they were laid and compacted satisfactorily; furthermore, these materials had dynamic stiffnesses 1½ and 2 times the predicted value for conventional dense bitumen macadam.

The corroborative work indicates that, provided there is sufficient binder to coat the aggregate, the expected performance benefits can be realised. None of the materials tested appeared to require more binder than that specified for dense roadbase macadam[1]. Given that suppliers adjust their target binder contents for presently specified materials to allow for the particular binder demands of their aggregates, there should be little risk of unsatisfactory materials with filler contents of up to 10 per cent incorporated in the specification.

3.3 Design considerations

Measurements of the dynamic modulus of the materials have been used in linear elastic analyses of flexible pavement structures designed according to Road Note 29[8] to carry heavy traffic. If the performance criterion is the ability of the roadbase and surfacing to protect the road foundation, then these calculations indicate that, for a given vertical stress in the subgrade, the thickness of bound layers could be reduced by about 20 per cent if a conventional bitumen macadam roadbase and basecourse containing 100 pen bitumen and 3 per cent filler were replaced by a macadam containing 50 pen bitumen and 8 per cent filler. Alternatively, if the thickness of roadbase were kept constant, the increases in stiffness should lead to an appreciable extension of pavement life. Corresponding benefits could also be achieved with tarmacadams of higher filler content employing tars of increased viscosity.

4. RESISTANCE TO FATIGUE CRACKING

It has been established[9] that in uniaxial fatigue tests under constant stress conditions and at a given temperature, the prime factor controlling the onset of cracking in bituminous materials is the maximum dynamic tensile strain in the specimen at the start of the test. The laboratory fatigue performance of a particular material may be characterised by the relationship between tensile strain, ϵ, and number of load cycles to failure, N, which is of the form

$$N = k\left(\frac{1}{\epsilon}\right)^n$$

where k and n are constants.

In the present work twelve beams removed from each pilot-scale pavement containing a bitumen binder were loaded in direct sinusoidal tension and compression, with dynamic stress amplitude kept constant until fracture. Only well-compacted materials were tested; but compaction has been shown to have little effect on fatigue life[10] and the results shown in Figure 7 should apply equally to all of the bituminous materials. For a particular value of dynamic strain, the Figure indicates that the conventional macadam containing 100 pen bitumen and 3 per cent filler has almost the same fatigue life as that containing 50 pen bitumen and 8 per cent filler. The 50 pen material containing 3 per cent filler appeared to have rather less resistance to cracking. However none of the differences are large in relation to the scatter in the experimental data, and any decrease in fatigue life that might have been caused by an increase in binder hardness would appear to have been offset by the addition of more filler.

In a fully flexible pavement any direct effect of binder hardness or filler content on fatigue life of the roadbase material is insignificant in comparison with the effect of increased stiffness, which reduces the strains induced in the material at the bottom of the roadbase, the zone most susceptible to fatigue cracking. To illustrate the possible magnitude of the effect, a flexible pavement designed to carry heavy traffic was analysed using typical traffic loading and temperature distributions and laboratory determined material properties[11]. The analysis predicted that, to maintain the same fatigue life, a basecourse and roadbase using 50 pen material and 8 per cent filler, could be about 20 per cent thinner than the conventional alternative: if there were no reduction of pavement thickness the pavement life would be considerably extended.

5. RESISTANCE TO DEFORMATION

Internal deformation of the bituminous layers contributes significantly to the deformation measured at the surface of a road pavement; the resistance to deformation of coated macadams is therefore important in determining the performance of flexible pavements. To investigate the effect of binder viscosity and filler content on the deformation resistance of coated macadam, wheel tracking tests[12] have been carried out on 24 slabs of bitumen macadam and 20 slabs of tarmacadam removed from the pilot-scale pavements. Each slab was 66 cm long x 80 cm wide x 15 cm deep. In the test these slabs are trafficked by a 21 kN wheel load applied through a pneumatic tyre inflated to 690 kN/m^2. The wheel passes to and fro over the test sample, moving 4.5 mm laterally between passes to cover a width of 150 mm. The test duration is usually 1,000 cycles. The test temperature is 30°C, simulating summer conditions in a basecourse. Deformation is measured in the central region of the slab at intervals during a test.

Previous studies have shown[12] that, for coated macadams of a given grading and with a range of binder contents, deformation is proportional to VMA. The results for the bitumen macadams plotted on this basis in Figure 8 confirm that deformation increases with increasing VMA but suggest that the other variables studied are also important. When the results are plotted in terms of PRD in Figure 9 the picture is clearer: the effect of reducing binder penetration is small but the increase in filler content reduces deformation by 30 to 40 per cent for materials receiving the same compactive effort.

The results for the tarmacadams, plotted in terms of PRD in Figure 10, are more complex but show a broadly similar effect on deformation resistance of increasing compaction and filler content. Comparison of the deformations at a PRD of 95, a realistic level of compaction on site, shows that adding filler to the material containing 54 evt tar reduced the deformation from 5.7 to 3.6 mm (materials 4 and 5); this confirmed the conclusion obtained for bitumen macadam. Material 6 contained the lowest amount of 58 evt tar and had the highest filler content and was, as expected, one of the least deformable materials. Material 8 had a less finely graded aggregate and the most binder and consequently deformed significantly more than the other high filler materials, with one sample showing evidence of flushing. At 95 PRD materials 6 and 8 deformed by 3.2 and 4.7 mm respectively, with material 7 deforming by 3.6 mm. Bearing in mind the variability of individual results in Figure 10, the difference between the viscosities of the two tars appears to have had little or no effect. The findings with the tarmacadams agree with those for the bitumen macadams and also support previous work[12] that indicated a deterioration in resistance to deformation with increase of binder content for some crushed rock materials.

6. CONCLUSIONS

1. Results obtained for roadbase materials covering a wide range of binder and filler content and several aggregate types indicate that binder contents within the present specification range would be sufficient to coat most aggregates containing up to 10 per cent filler. Bitumen and tarmacadams having a higher filler content and a higher viscosity binder would be as compactable as conventional dense coated macadam providing the temperatures at mixing and rolling were increased to compensate for the greater viscosity of the binder.

2. The present results suggest that advantages could be derived from varying the specification of dense coated macadam roadbase and basecourse to include higher viscosity binders and higher filler contents; the additional filler that would be required and the higher viscosity binder are understood to be readily available. The new roadbase material would be particularly useful in the reconstruction of heavily trafficked motorways; it has the following properties.

   a) Load-spreading ability is significantly greater than that of typical dense coated macadam; the stiffness modulus is approximately doubled. Such an increase leads to a reduction in the traffic stresses transmitted to the lower layers of the pavement, allows an appreciable reduction in design thickness or an extension of life at a given pavement thickness.

   b) Laboratory fatigue resistance for a given dynamic strain is almost the same as for conventional dense bitumen macadam containing about 3 per cent filler and a 100 pen bitumen, but the greater stiffness of the improved material reduces the tensile strains induced at the bottom of the roadbase by traffic. Therefore to maintain the same fatigue life, a roadbase containing the new material could be thinner than the conventional alternative. Of possibly greater significance, is the appreciable extension of pavement life to be expected from use of the improved material at present design thickness.

   c) Internal resistance to deformation is better than for conventional dense coated macadam.

7. ACKNOWLEDGEMENTS

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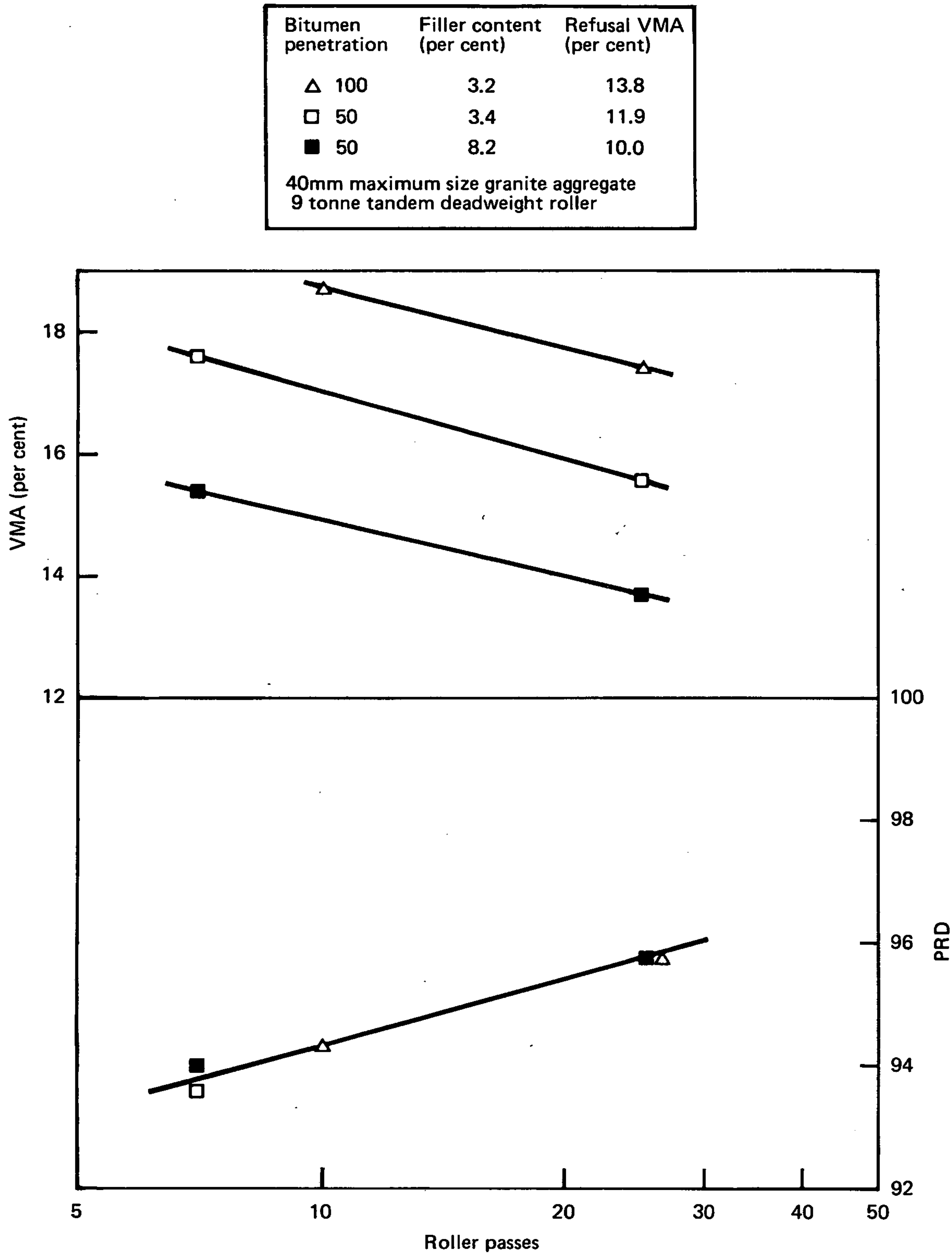

Fig.1 Variation of VMA and PRD with roller passes for bitumen macadams

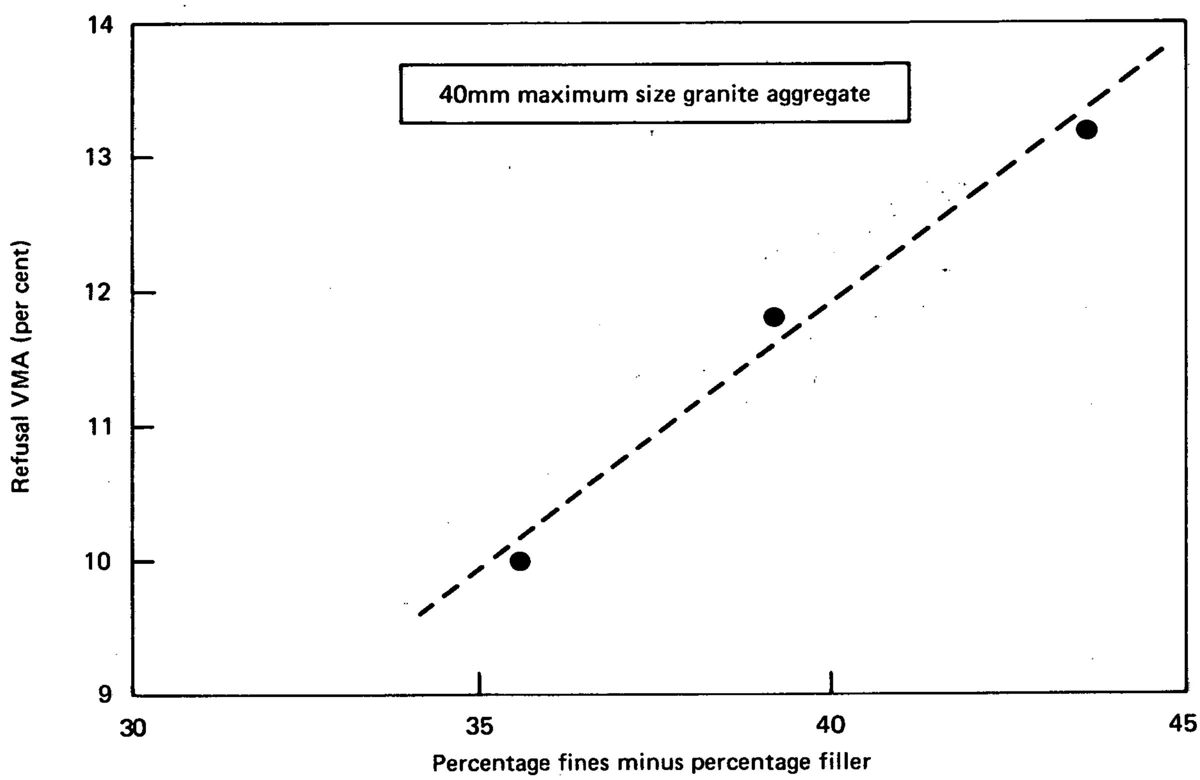

Fig.2 Relation between compactability and grading of fine aggregate fractions

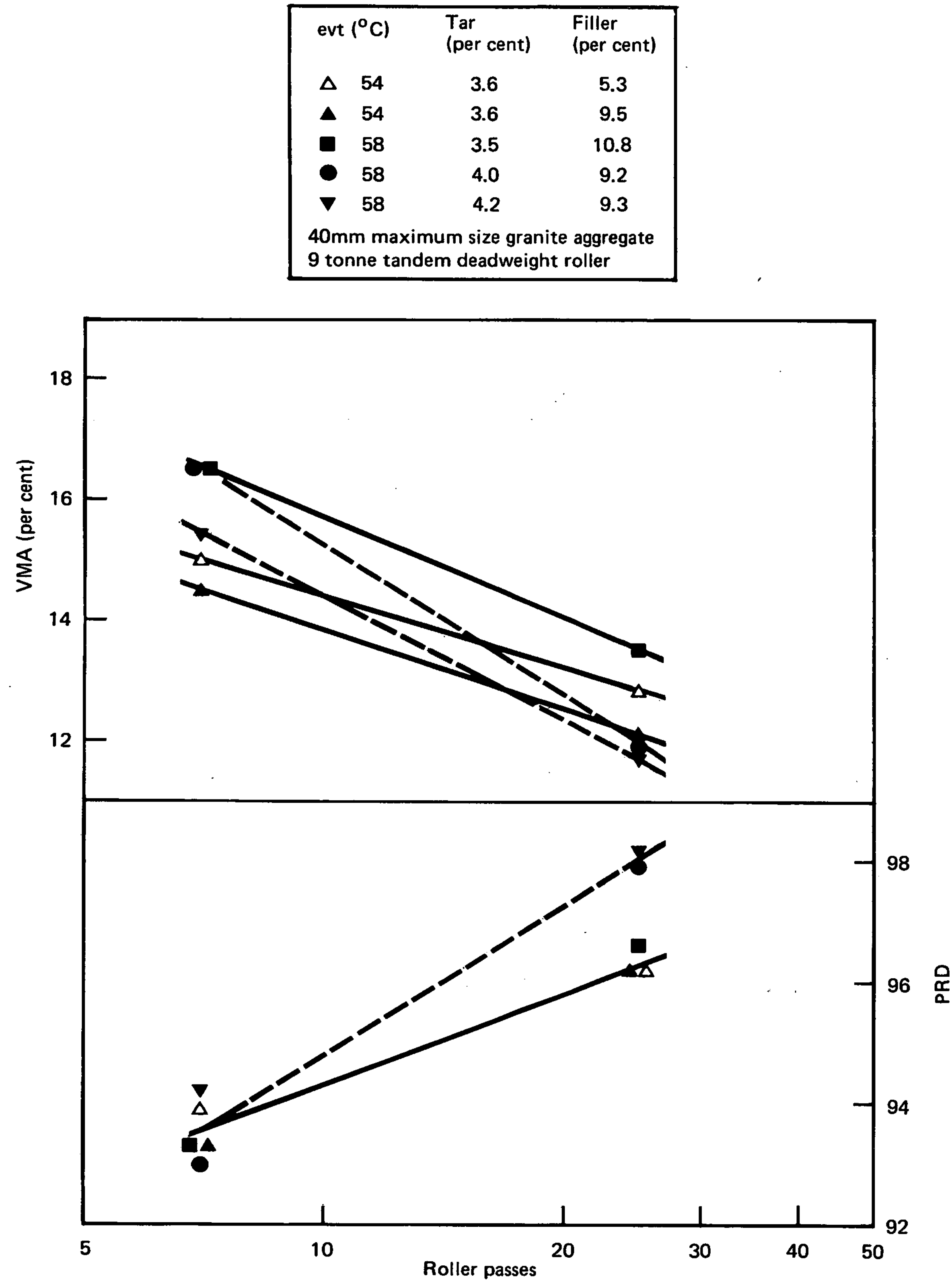

Fig.3 Variation of VMA and PRD with roller passes for tarmacadams

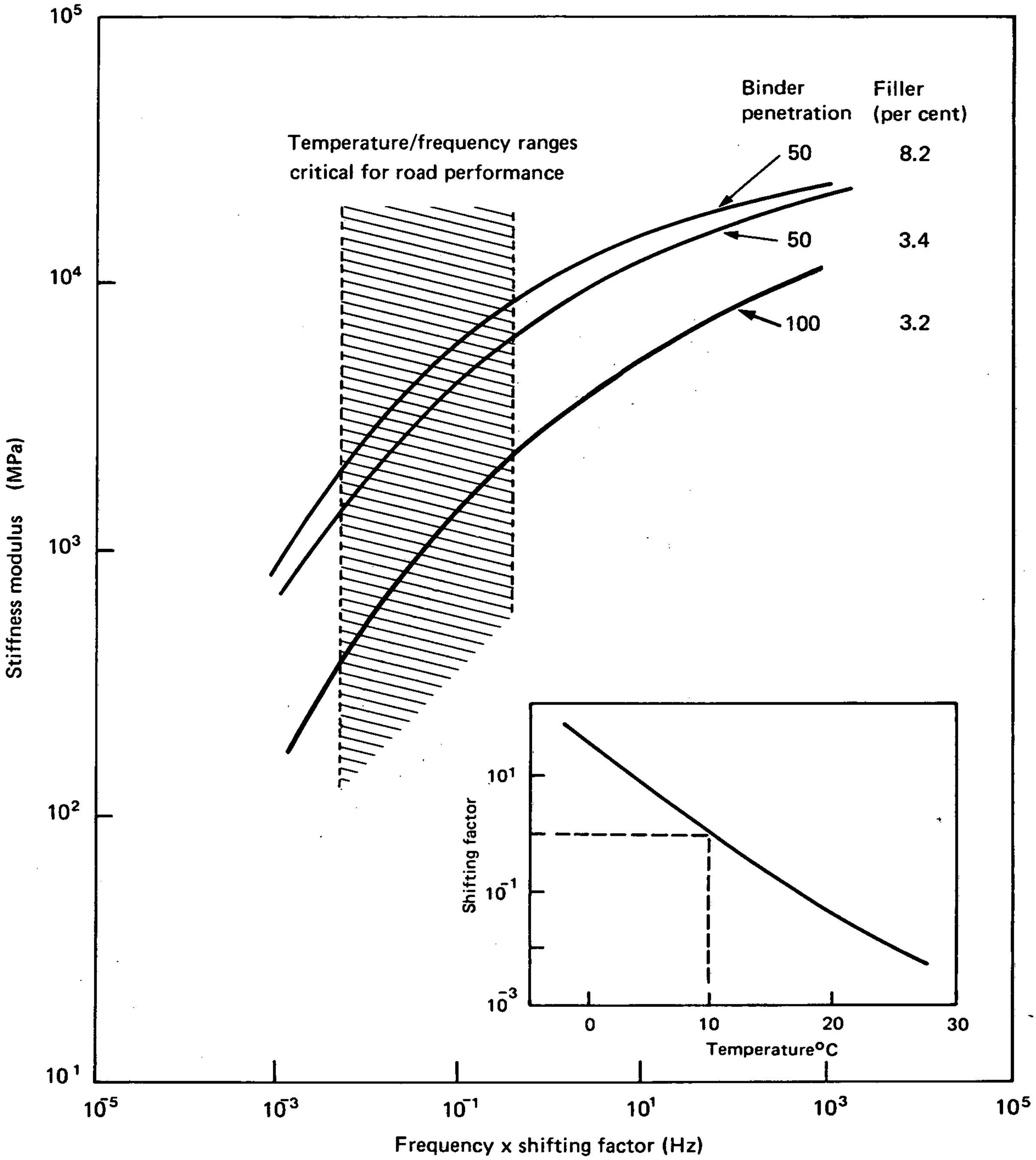

Fig.4 The effect of binder penetration and filler content on dynamic stiffness of well compacted bitumen macadam

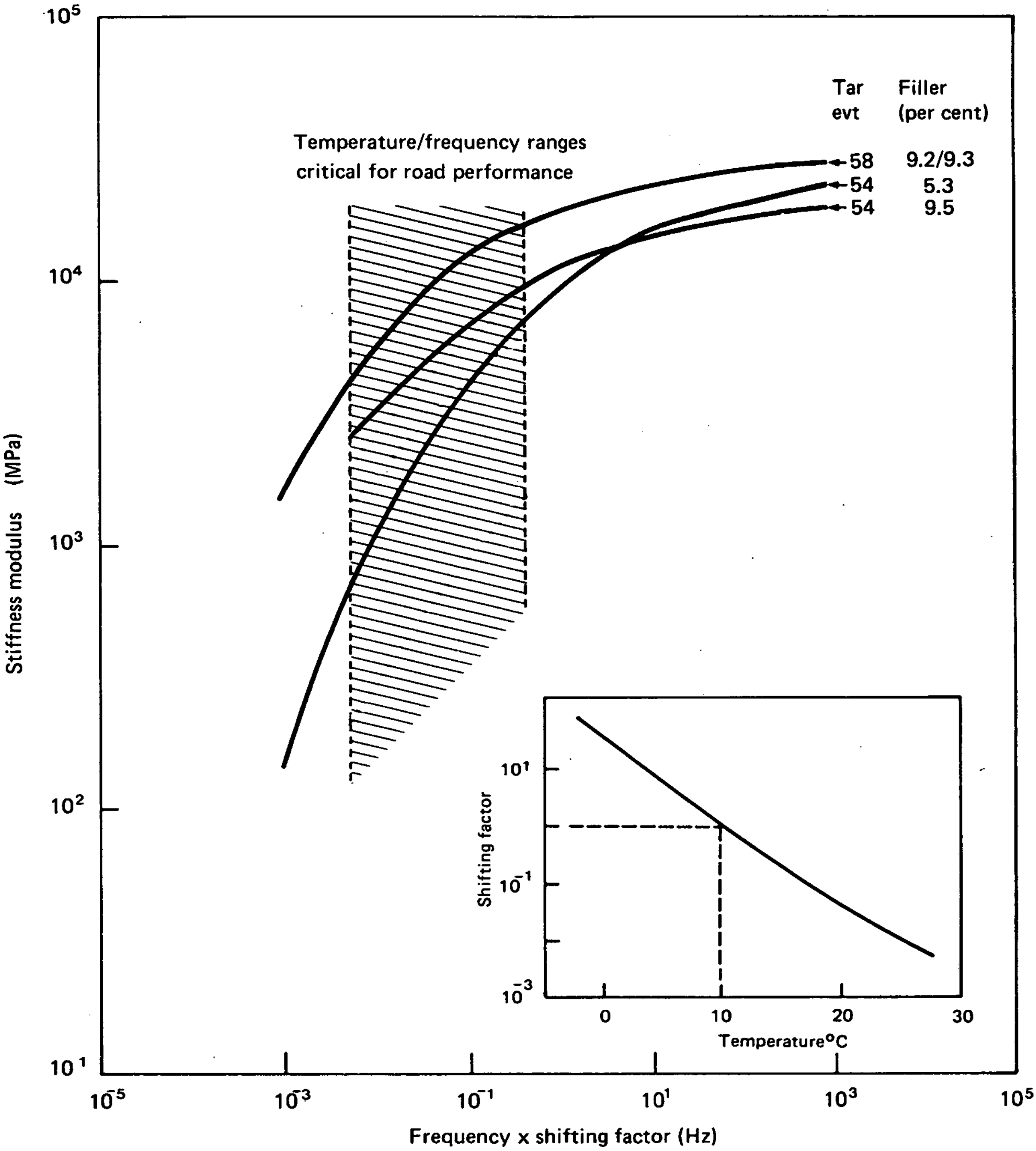

Fig.5 The effect of binder viscosity and filler content on dynamic stiffness of well compacted tarmacadam

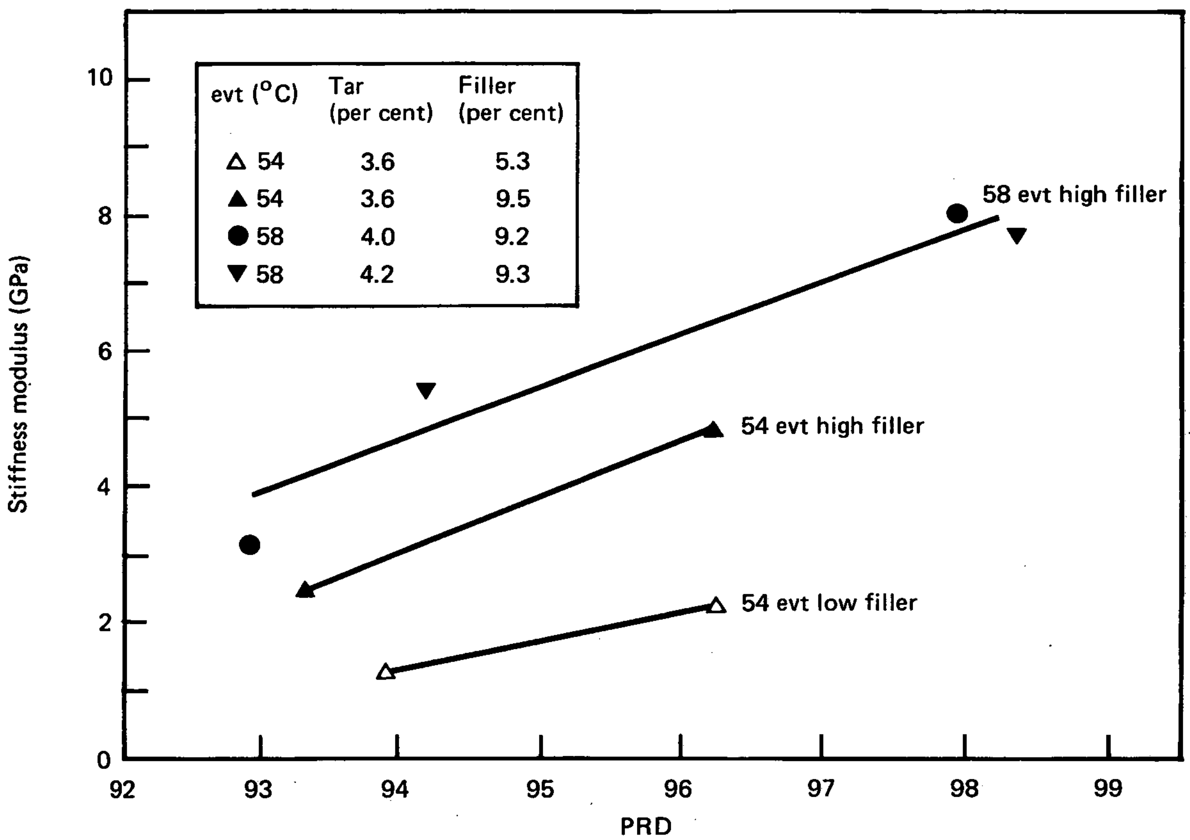

Fig.6 Effect of compaction on dynamic stiffness of tarmacadam at 5Hz and 25°C

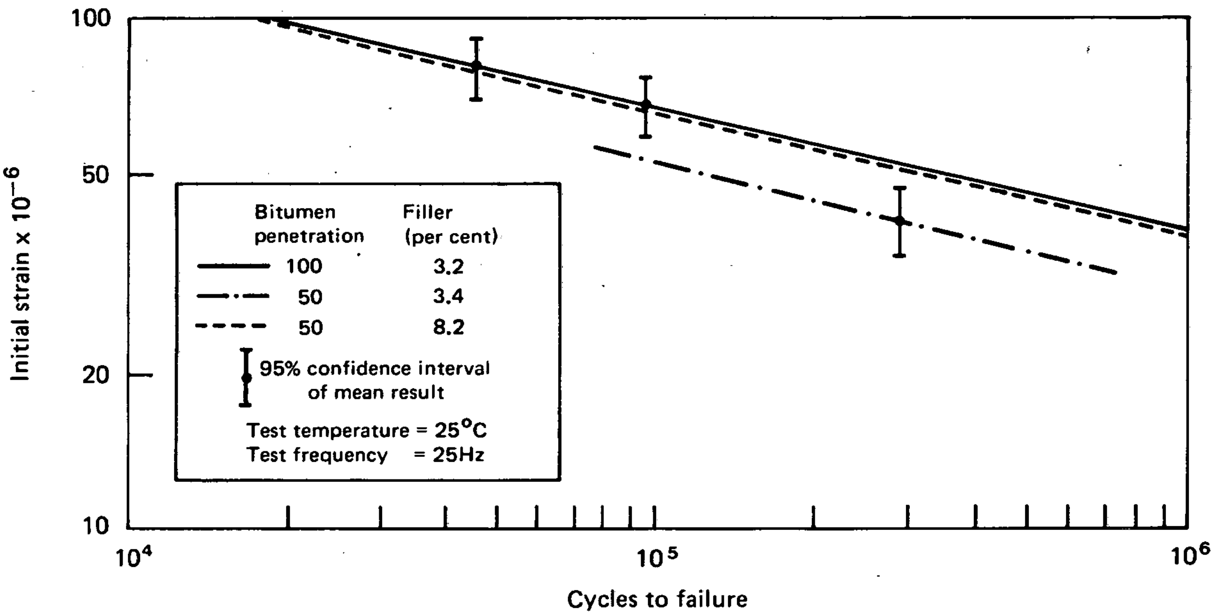

Fig.7 The effect of binder penetration and filler content on laboratory fatigue resistance of bitumen macadams

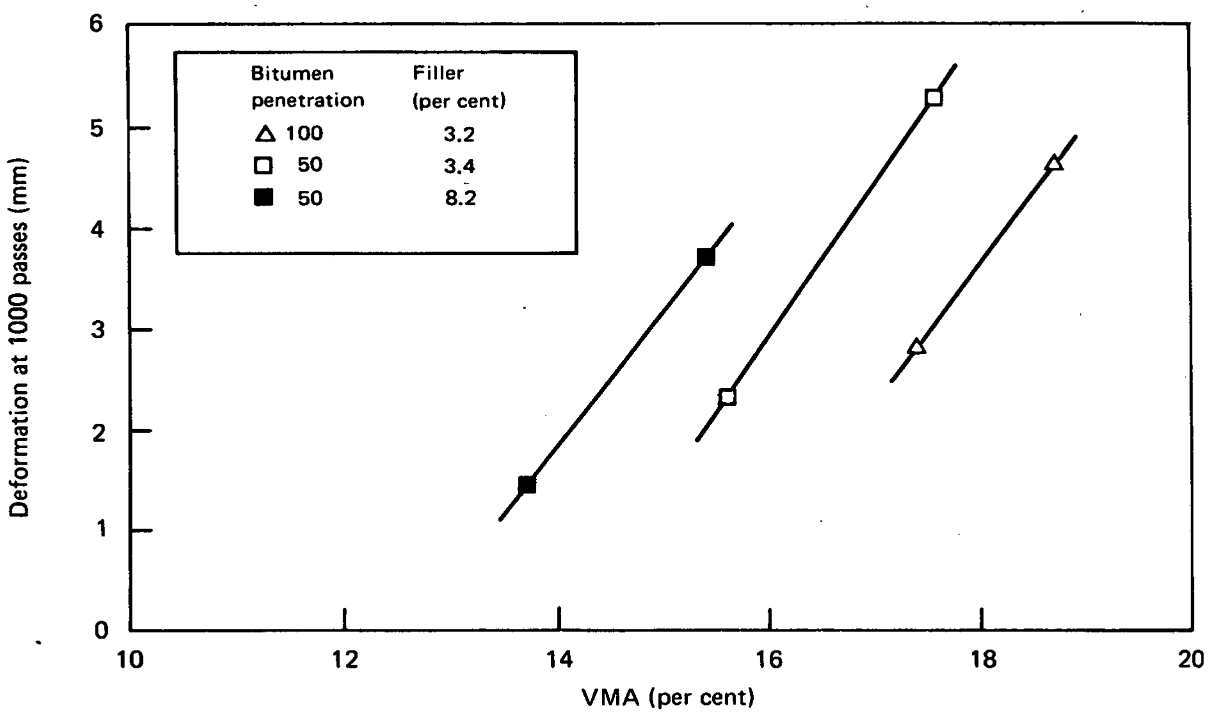

Fig.8 The effect of binder penetration and filler content on deformation resistance of bitumen macadams

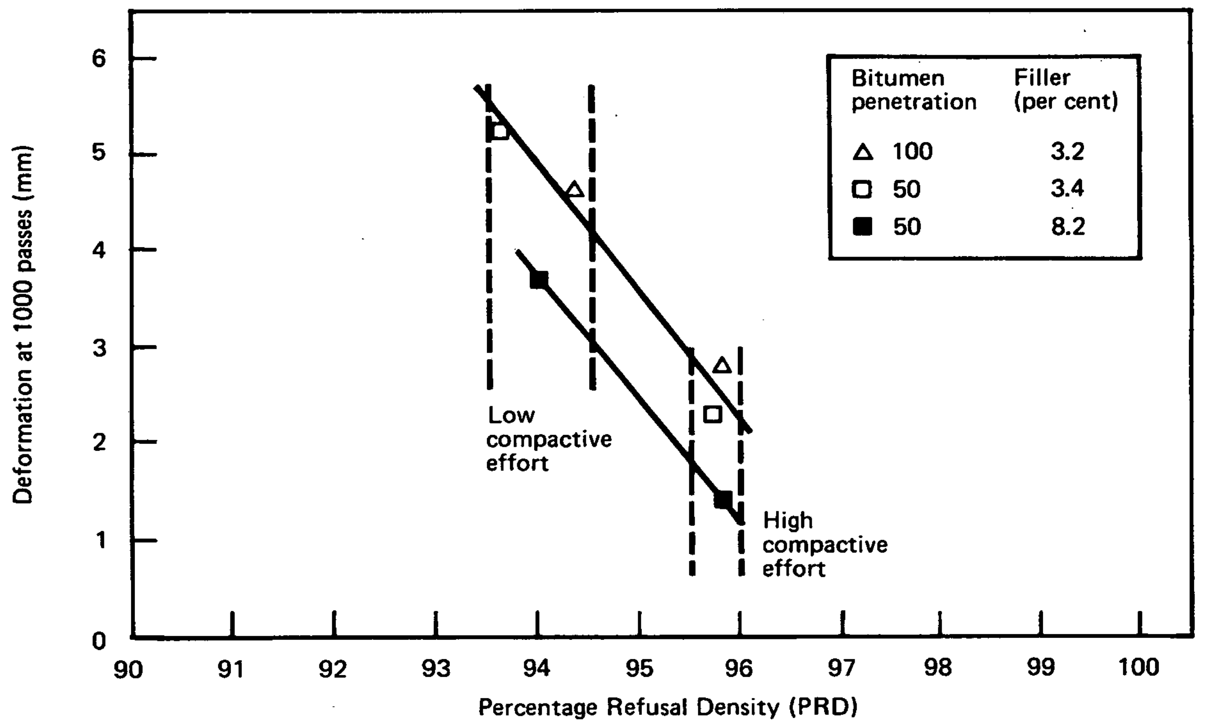

Fig.9 Variation of deformation with PRD for bitumen macadams

	evt (°C)		Tar (per cent)	Filler (per cent)
4	△	54	3.6	5.3
5	▲	54	3.6	9.5
6	■	58	3.5	10.8
7	●	58	4.0	9.2
8	▼	58	4.2	9.3

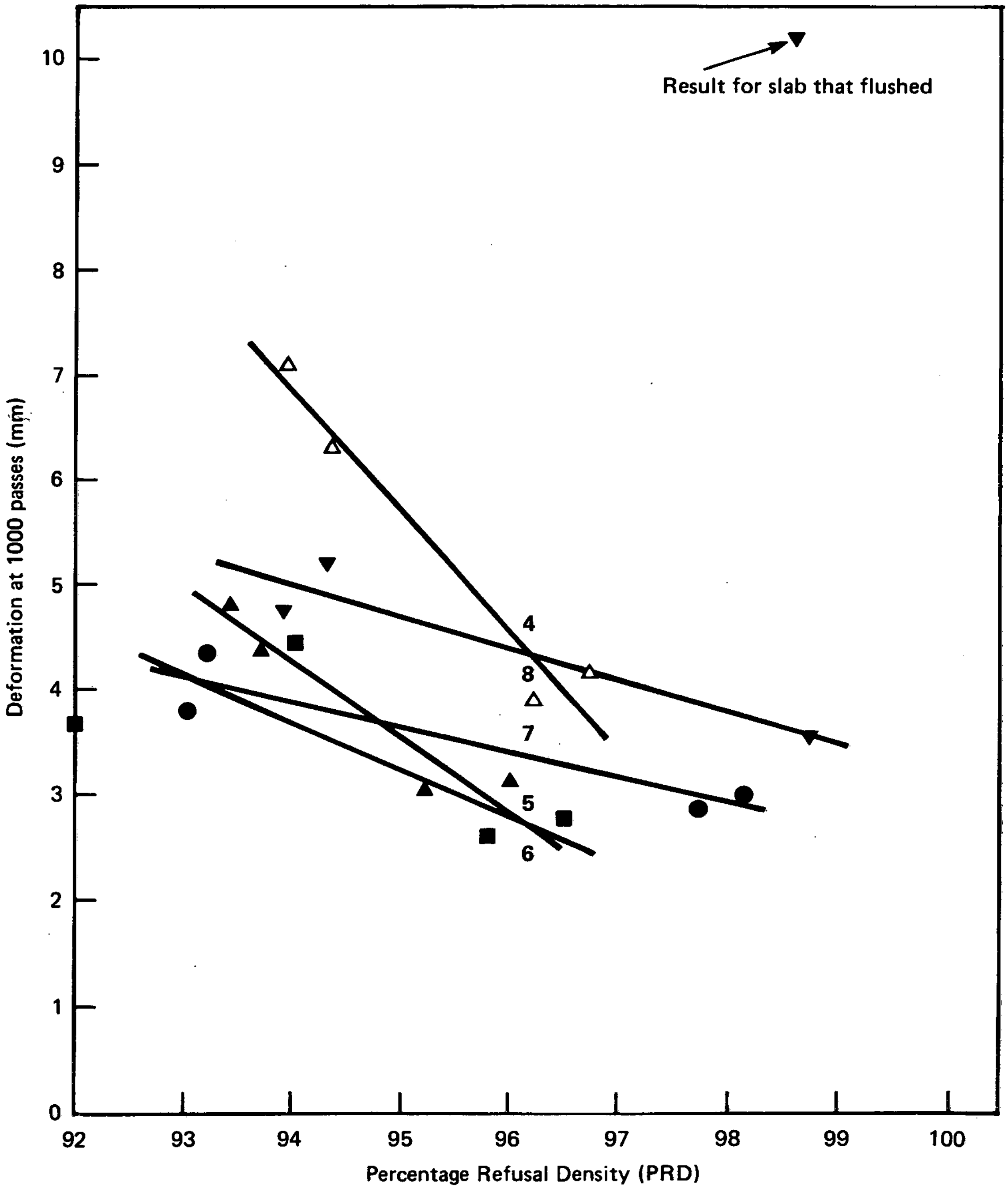

Fig.10 Variation of deformation with PRD for tarmacadams

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ABSTRACT

A dense coated roadbase macadam of improved performance: D LEECH: Department of the Environment Department of Transport, TRRL Laboratory Report 1060: Crowthorne, 1982 (Transport and Road Research Laboratory). An assessment has been made of the effects of binder hardness and filler content on the performance of dense coated roadbase macadams containing 40 mm crushed granite aggregate and limestone filler with either bitumen or tar binder. The materials were laid and compacted using full-scale plant; they included 50 and 100 penetration bitumen, 54 and 58 evt low temperature tars and filler contents in the range 3 to 11 per cent. Samples were cut from the laid materials to measure deformation resistance, dynamic stiffness and resistance to fatigue. Corroborative work with other crushed aggregates provided more data on dynamic stiffness and reassurance concerning possible mixing problems.

Binder contents within the present specification range are sufficient to coat most aggregates containing up to 10 per cent filler and dense roadbase macadam with the binders of higher viscosity and about 8 per cent filler confers significant benefits through better load spreading and deformation resistance. Furthermore, at equiviscous temperatures of rolling, the material was shown to be as easy to compact as conventional dense coated macadam. In heavily trafficked roads, its use would allow significant reductions of design thickness or, alternatively, a marked extension of pavement life.

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