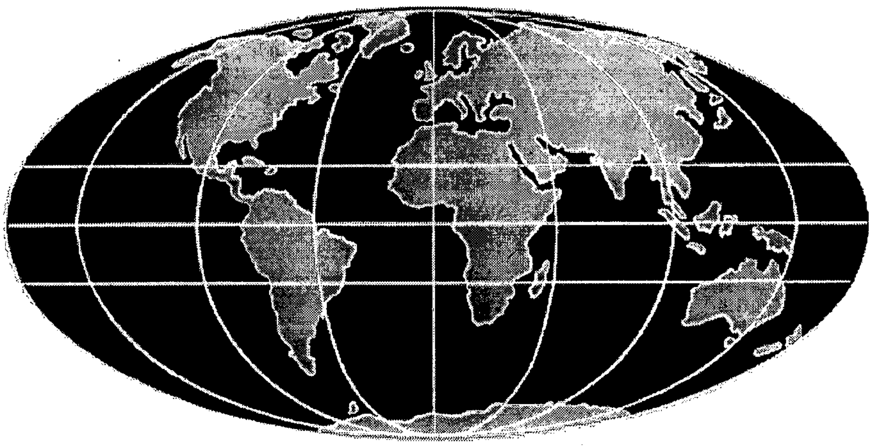
TRANSPORT RESEARCH LABORATORY

TITLE: Kenya asphaltic materials study

by: J Wambura, J Maina and H Smith



Transport Research Laboratory
Crowthorne
Berkshire RG45 6AU
United Kingdom

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KENYA ASPHALTIC MATERIALS STUDY

1. INTRODUCTION

The Ministry of Public Works and Housing (MoPW&H) and the Transport Research Laboratory (TRL), with funding through the European Commission for Development, have carried out a study to identify the causes of premature cracking and, in particular, of plastic deformation in asphaltic hot mix surfacings in Kenya.

Several newly constructed sites, particularly along the heavily trafficked corridor from the port of Mombasa to Malaba at the border with Uganda, have suffered severe plastic deformation in the asphalt concrete (AC) surfacing. This form of failure is particularly serious because once ruts become too deep for safe usage it is necessary to remove the deformed material before rehabilitation can be effected.

2. BACKGROUND

In previous MoPW&H/TRL studies, in the 1970's and early 1980's, failures of asphaltic surfacings were nearly always associated with cracking which initiated at the surface of the layer. Mix design was based on 50 blows of the Marshall compaction hammer which gave a higher design asphalt content than would be obtained with 75 blow compaction, which is normally recommended for the design of surfacings for high traffic loading. Even with 'high' asphalt contents obtained with 50 blow compaction, 'top down' cracking often developed early in the life of the surfacings. This was shown to be related to severe hardening of the asphalt in the top few millimetres of the wearing course[(1)] and occurs even in dense mixes [(2)]. Although annual unidirectional traffic loading was some 0.8×10^6 equivalent standard axles (esa) and axle loads were frequently of 14 tonnes or more, cracking was the dominant form of failure and plastic deformation was confined to steep climbing lanes.

3. CONFIRMATION OF CAUSES OF CRACKING.

Two of the heavily trafficked sites investigated in this study had suffered cracking which was typical of the behaviour of the earlier trials. On one site the cracking started within a few months of construction but after being sealed with a surfaced dressing it has now given good performance for more than ten years. However, the same AC deformed plastically where it was placed on a climbing lane. Significantly some 85 per cent of cores cut at the time of construction had VIM between 5 and 10 per cent and although 5 per cent is rather low the values are largely in line with the recommendations of the Asphalt Institute. The AI recommends that to allow for secondary compaction under traffic, VIM at the time of construction may have to be of the order of 8 per cent[(3)].

Cores taken from an area of cracking on a second climbing lane showed that cracks had started at the top of the layer. In this case, after many years of trafficking, VIM was of the order of 3.7 per cent. The cores were cut horizontally into sections to enable determination of the asphalt viscosity gradients in the cores. The data obtained is shown plotted in Figure 1. Severe hardening of the asphalt, from typically 7.5 x 10^4 poises immediately after construction to 10^7 within about 2 years had occurred in the top few millimetres of the materials. This is typical of the results from the earlier studies in Kenya.

Although the largest tensile strains under a loaded wheel will occur at the bottom of the AC layer, other tensile strains are induced at the surface as the road deflects transiently under a load. At certain times of the day thermal stresses can also generate tensile strains in the layer. The indications are that strains induced by very heavy wheel loads, or in combination with thermally induced strains, are large enough to cause the brittle surface of an age hardened mix to crack.

4. INVESTIGATION OF DEFORMED SECTIONS

Plastic failure of an asphaltic surfacing occurs when heavy vehicles compact the material to a point where the air voids content in the mix is too low. At this stage the fines and asphalt matrix are carrying more of the imposed traffic stresses and start to reduce the stone to stone contact of the coarse aggregate particles which can result in a catastrophic reduction in mix stability and plastic deformation(4).

A common specification for AC wearing courses was used on the heavily trafficked route from Mombasa to Malaba, which passes through a range of climatic zones. Minimum and maximum mean monthly temperatures range from 22°C-30°C at the coast and 8°C-18°C in the highlands. The fact that traffic loading was similar on most of the sites and that different material sources, plant and construction teams were involved at each site indicates that the underlying problem was associated with mix design.

It was not possible to establish exactly why such a sudden change in the performance of AC surfacings has occurred in Kenya during the last few years. However, it is postulated that there has been a perceived requirement to improve the durability of wearing courses in Kenya. Many practising engineers had become aware of the frequent occurrence of cracking in AC wearing courses and it is possible that this knowledge had created a tendency to use asphalt contents at the high end of the currently permitted range. In addition, more aggressive loading resulting from changes in vehicle characteristics and tyres will have effectively increased the sensitivity of AC surfacings to changes in volumetric composition.

4.1 Possible traffic effects

Commercial vehicles in Kenya are generally heavily overloaded, and this makes the task of designing satisfactory dense AC surfacings an exacting one. However, there are two factors which, it is suggested, may have contributed to the poor performance of recently laid AC surfacings;

(a) An increase in multi axle vehicles with triple and even quadruple axle sets. The effect of multi axle sets is to increase loading times under individual vehicles, which would contribute to the deformation of susceptible surfacings.

(b) Vehicle wheels, fitted with a cross-ply tyres tend to 'climb' out of a rut. This tends to make the wheel path wider and spreads the loading. Radial-ply tyres, however, tend to run in the bottom of the rut [5] and therefore concentrate the wheel loads over a very narrow wheel path.

A MoPW&H survey carried out in 1987 showed that on 200 vehicles, 58% of the outside wheels were fitted with biased (cross-ply) tyres and 42% with radial ply tyres. This is a higher percentage of radial-ply tyres than would have been found even a few years earlier and is likely to have increased since 1987. The survey also showed that tyre pressures were high with 10 per cent being in excess of 830 kPa (120 psi), with a maximum of 970 kPa (145 psi). The changes in vehicle characteristics, tire type and tire pressures are clearly placing ever increasing demands on road surfacing materials in Kenya.

4.2 Site and laboratory materials testing

Core samples were cut from the wheel-paths of sections carrying the same traffic on similar vertical alignments but where the asphaltic surfacing was in different condition. The rut depth was measured at each coring location. The cores were used to determine mix composition, VIM by using the 'Rice' method[6] and the penetration of asphalt recovered from each complete layer.

Data obtained for the cores is plotted in Figure 2. The tests were necessarily made at a 'point in time' and no allowance could be made for the different number of esa's carried by the sections. Two results for the cores taken from the carriageway at Muguga have been highlighted on the Figure because, although the VIM values are very low, rutting is not yet severe. However, a rut of 24mm depth had developed at an adjacent test point and the appearance of the surfacing suggests that extensive plastic deformation will develop in the near future.

The results show a strong relationship between VIM and the magnitude of rut depth, or plastic deformation, for eleven sites. They support the generally held view[7,8] that if VIM is reduced to less than 3 per cent there will be a high risk of plastic deformation under heavy traffic.

The relationship between values of VIM, Voids in the Mineral aggregate (VMA) and the penetration of asphalt recovered from the complete layers in each core sample, are shown plotted in Figure 3. Two data points are highlighted because the asphalt contents of the two cores, at 3.9 and 4.4 per cent are very different to the remaining data set, for which asphalt contents ranged from 5.5 to 6.8 per cent.

The effect of VIM on the rate of asphalt hardening is also illustrated in the Figure. Although there is scatter in the results, penetration values can be divided into two broad groups. Asphalt recovered from cores with VIM of less than 2 per cent, had penetration values between 51 and 92, whilst for VIM of more than 3 per cent corresponding values lie between 46 and 17.

4.3 Difficulties with mix design

At present the Marshall test is used in many countries and it will be some time before other methods of mix design and performance testing, such as those recommended for use with the SUPERPAVE®

System[9], become generally available.

There are considerable difficulties in ensuring that an optimum mix design can be obtained for heavily trafficked roads when using the Marshall test. This is because of the need to select an appropriate number of blows of the compaction hammer. The AI recommends that the level of compaction to be used in the test should produce a mix density equivalent to that which will occur after secondary compaction by traffic. Effectively this means that a core cut from an AC surfacing *after* secondary compaction by traffic should ideally have an air voids content of 4 per cent and not less than 3 per cent if plastic deformation is to be avoided. To achieve this the AI suggests that VIM may have to be as high as 8 per cent at the time of construction. Unfortunately, in tropical environments AC surfacings with such a high initial VIM will show premature deterioration through asphalt ageing. An important consideration is that although compaction will occur in the wheel paths, untrafficked areas will retain the high initial air void content, especially where wheel paths are narrow as a result of the growing use of radial ply tires. In addition, as the results of the present investigation indicate, the designer will not be able to predict the combined effects of the rate of asphalt hardening and the rate of secondary compaction. This will be particularly difficult where the geometry of the road changes frequently and, therefore, vehicle speeds, loading times and the rate of secondary compaction are variable.

If the initial VIM is high and traffic loading is not severe, then the rate of reduction in VIM may be slow enough to allow asphalt hardening to take place. This may stiffen the mix sufficiently to prevent a potential reduction in VIM to less than the critical 3 per cent. Heavy and intense early trafficking is likely to reduce VIM rapidly and may prevent appreciable asphalt hardening. Mix stiffness may not then increase sufficiently to prevent a critical reduction in VIM.

4.4 Implications for mix design

The results illustrate that AC wearing course materials can be very sensitive to changes in mix composition, and that it is essential to obtain the correct volumetric composition for the traffic loading,[9,10]. This implies a high level of quality control and detailed knowledge of material behavior. There will be many occasions in many countries where this will not be a realistic expectation. In the absence of sufficient knowledge mix design will continue to be based on a maximum of 75 blow Marshall compaction, which may be inappropriate for the traffic loading.

It is recommended that a more robust design procedure is used and that mixes which are less sensitive to errors in composition are adopted for severe loading conditions. It is further recommended that surface dressing is used to protect the asphaltic layer from premature cracking associated with age hardening.

5. INTRODUCTION OF NEW MIX DESIGN PROCEDURE

5.1 Effect of compaction effort and aggregate grading

Authorities in the Middle East have recommended the use of refusal compaction as representing the ultimate density after secondary compaction on severely loaded sites[11]. This involved using 500 blows of the Marshall compaction hammer to each face of the Marshall test briquette. Whilst it is considered that there is a need for reference to refusal compaction, the use of an electric vibratory hammer is preferred to extended Marshall compaction because;

(a) It is a rapid process using an electric vibrating hammer of 750 watts output.
(b) Because the compaction foot is of a smaller diameter (100mm) than the mold a kneading action, which is more like the mode of compaction under a roller, is imparted to the sample.
(c) The compaction method is relatively insensitive to temperature and layer thickness[12] and is therefore a more robust laboratory test.
(d) The method offers an effective procedure for aiding quality control in the field.
(e) Materials containing particles larger than 25 mm, the maximum permitted in the Marshall test, can be accommodated.

The vibrating hammer test method is outlined in Road Note 31[8] and is a slightly modified form of the procedure described in BS 598 [13]. An important feature of the test is that below a critical asphalt content the VMA for a given aggregate structure remains sensibly constant. This means that the refusal test can provide a *reference density.*

A laboratory test programme was carried out to demonstrate the effect of different levels of compaction on the selection of a design asphalt content. Compaction levels used in the study included 50, 75, and 200 blow Marshall compaction in standard size molds, and vibrating hammer refusal compaction in 150mm diameter split molds.

It is generally accepted that the sensitivity of AC mixes is affected by the grading of the aggregate in the mix. If the grading follows the Fuller curve closely, it is usually so dense that there is very little room for asphalt and such a mix is both difficult to compact and very sensitive to errors in composition.

The effect of VMA on the relationship between VIM and asphalt content for different aggregate mixes, when compacted to refusal density, is shown in Figure 4. It is clear from this Figure that if secondary compaction reduced the VIM of the wearing course Mix 1 to 3% VIM at refusal density then the mix would not be viable. This is because at 3 per cent VIM the permitted asphalt content would only be approximately 2.9 per cent and the mix would not be workable. In comparison, binder course mix 6 would retain 3 per cent VIM at refusal density at an asphalt content of approximately 4.7 per cent which should make the mix workable.

To optimize mix properties for severe traffic loading aggregate gradings should be adjusted away from the Fuller curve. Recommendations provided by the Strategic Highway Research

Programme[9] can help to achieve this.

5.2 Compaction test results

Results are presented in Figure 5 for four levels of compaction applied to a wearing course mix containing aggregate obtained in Kenya. The aggregate grading closely followed the Fuller curve and passed through the SUPERPAVE® restricted zone. At an asphalt content of 5.4 per cent VIM is reduced from 4 per cent to 1.5 per cent when Marshall compaction is increased from 50 to 200 blows. However, compaction to refusal density with the vibratory hammer reduced VIM to virtually zero. Clearly any underestimate of the degree of secondary compaction under traffic could easily result in this mix deforming plastically.

Investigations of other gradings confirmed the general results presented in Figure 4 that acceptable results were most easily obtained with coarser aggregate gradings of the binder or road base types which fell below the SUPERPAVE® restricted zone. Figure 6 shows the relationship between VIM and asphalt content for three roadbase mixes which had a maximum particle size of 37.5mm. The mix RB1 had a fine grading above the restricted zone, the grading of RB2 went partly through the restricted zone and that of RB3 fell below the restricted zone. Mixes RB1 and RB2 could be expected to be laid at asphalt contents which would allow them to be workable and to retain 3 per cent VIM after secondary compaction.

6. DETERMINATION OF MIX PROPERTIES

6.1 Tests to determine mix properties

Ensuring that the composition of a mix is correct and that the VIM value will not fall below 3 per cent on severely loaded sites is a vital part of the design process. However, the degree of aggregate interlock and friction between particles has an important bearing on the resistance to shear failure of an asphaltic mix. Uncrushed rounded gravel could meet the minimum VIM requirement when compacted to refusal in a mold, but aggregate interlock may not be sufficient to prevent shear failure under heavy traffic. Additional tests are therefore required to determine the likely performance of asphaltic surfacings under heavy traffic[9]. To demonstrate this approach, a wearing course and two binder course mixes were manufactured in the laboratory and subjected to performance tests.

A wearing course mix, WC, and a binder course mix BC2 had aggregate gradings which fell below the SUPERPAVE® restricted zone. A second binder course material, BC1, had a considerably finer grading which passed through the upper part of the restricted zone. Mixes were made with 80/100 penetration asphalt and aggregates which were typical of materials produced in Kenya. The mixes were compacted in slabs by a roller compactor and six cores were then cut from each slab and subjected to the following tests;

(a) Density measurements.
(b) Creep and mix stiffness modulus.

(c) Wheel tracking at temperatures of 45°C and 60°C.
(d) Refusal density.

Creep and stiffness moduli were determined in a Nottingham Asphalt Tester(14,15). The refusal density of each material was also determined. A summary of the general test conditions are given in Table 1.

TABLE 1 General test conditions for measuring indirect tensile stiffness modulus of asphalt mixtures

Nominal specimen diameter (mm)	Width of loading face (mm)	Nominal depth of concave segment (mm)	Rise time (s)	Target peak horizontal deformation (mm)	Pulse repetition period (s)	Deformation measurements
150	19±1	0.6	124ms ±4ms	0.0075	3.0±0.1s	Better than 1 micron over the range ± 100 microns

6.2 Results of tests to determine mix properties

The test results for determinations of the physical properties of the cores, including VIM, VMA, Voids Filled with Asphalt (VFA) at roller and refusal densities, are summarized in Table 2.

TABLE 2 Details of cores cut from roller compacted samples

Mix No. and Asphalt content		Mean values for six cores from each mix				Values at refusal density	
	(%)	Percent of refusal density	VIM (%)	VMA (%)	VFA (%)	VIM (%)	VFA (%)
WC	4.1	94.7	7.6	16.4	54	3.3	72.0
	4.9	94.7	7.0	16.2	56.8	1.8	84.4
	5.4	95.8	4.3	15.9	73.0	0.1	98.9
BC1	3.4	97.2	6.1	13.6	55	4.3	61.3
	4.0	97.2	3.9	12.8	70	1.5	85.5
	5.1	98.9	0.8	12.4	94	0.0	100
BC2	3.2	96.7	7.0	13.9	50	5.2	53.0
	4.0	95.5	6.8	14.2	52.1	2.4	76.7
	5.1	96.4	4.2	14.8	71.6	0.6	94.9

It is recommended that mix density after compaction in the field should give a mean value of 95 per cent of refusal density and that no individual reading should be less than 93 per cent[8]. Roller compacted cores had densities which were close to or more than 95 per cent of refusal density.

To retain 3 per cent VIM at refusal density the wearing course mix WC would have to be made with approximately 4 per cent asphalt. Workability may be poor with this asphalt content and variations within normal plant tolerances could have a dramatic effect on the final characteristics of the mix.

Binder course mix BC2, with an aggregate grading which fell below the SUPERPAVE® restricted zone, was the least sensitive to change in asphalt content. However, very close control of the upper tolerance limit would have to be applied during manufacture. The results of the performance tests are summarized in Table 3.

TABLE 3 Results of tests to determine mix properties

Mix No. and Asphalt content		Mix Stiffness Modulus	Indirect Tensile Stiffness Modulus		Wheel tracking tests			
		30°C	20°C	30°C	45°C		60°C	
	(%)	(MPa)	(MPa)		Rut depth (mm)	Rate (mm/h)	Rut depth (mm)	Rate (mm/h)
WC	4.1	4.8	1160	460	1.3	0.6	1.1	1.1
	4.9				1.5	0.6	4.2	2.5
	5.4				1.4	0.3	2.9	1.7
BC1	3.4	7.0	1750	710	0.9	0.0	1.1	0.7
	4.0				1.1	0.5	2.1	1.0
	5.1				2.5	1.7	3.4	1.4
BC2	3.2	5.8	1440	550	1.4	1.0	1.2	0.9
	4.0				2.0	0.7	2.5	1.2
	5.1				1.7	0.5	1.9	1.1
For sites in the UK:								
Heavily stressed		4-5 (min.)			4 (max.)	2		
Very heavily stressed							7 (max.)	5

The test mixes gave good results in relation to UK requirements for 'heavy' and 'very heavily' stressed sites. At approximately the notional design asphalt contents for each material, the mix stiffness moduli and indirect tensile stiffness moduli of the binder course mixes were superior to those of the wearing course mix. Wheel tracking rates at 60° C were acceptable for all the mixes. It would of course be necessary to develop appropriate design limits for local conditions, rather than to adopt the UK recommendations.

7. RECOMMENDED MIX DESIGN PROCEDURE

The following mix design procedure is recommended for the design of AC surfacing materials for heavily loaded sites, and where equipment for design is limited. Mixes which are most likely to be satisfactory will be of the binder course or road base types. If the maximum particle size is 25mm or less the Marshall design procedure, using 75 blow compaction on each face, should be completed first to ensure the normal design parameters can be met. This, together with past experience, may be sufficient to indicate that the aggregate being used is satisfactory in terms of having good particle interlock.

Gradings above and below the SUPERPAVE® restricted zone should be used initially, but the available aggregate sizes may limit this choice. Use of large maximum sized particles preclude the use of the Marshall test and a modified grading should be used to give only a general indication of aggregate suitability.

After the Marshall optimum binder content has been determined[(3)], samples are made with asphalt contents starting at the optimum and decreasing in 0.5 per cent increments. These samples are then subject to vibratory compaction to establish the asphalt content at which 3 per cent VIM is retained at refusal density.

A judgement will have to be made as to whether or not the mix which gives 3 per cent VIM at refusal density would be workable. If there is any doubt about this alternative gradings, with increasing VMA, should be tested until a viable mix is identified.

The testing of the design mixes in pre-construction field trials is extremely important. At least three trial lengths should be constructed with asphalt contents at the laboratory optimum for refusal density (3 per cent VIM) and at 0.5 per cent above and below the optimum. The trials should be used to;

(a) Determine the rolling pattern required to obtain a satisfactory density.
(b) Establish that the mix has satisfactory workability to allow a mean of at least 95 per cent and an absolute minimum of 93 per cent of refusal density to be achieved after rolling.
(c) Obtain 150 mm diameter cores so that the refusal density can be re-determined.

After measuring the density of cores cut from the trials they should be subjected to refusal compaction. This is important because the road rollers may have produced a different particle orientation compared to that produced in the laboratory tests. The cores are heated in the compaction mold and compacted to refusal so that the maximum binder content which allows 3 per cent VIM to be retained at refusal density can be confirmed. This is simplified by the fact that samples compacted to refusal density will have sensibly constant values of VMA over a range of asphalt contents, before the aggregate structure begins to become 'over-filled' and VMA increases. If necessary further adjustments to the design grading should be made and retested in field trials.

8. IMPLICATION OF REFUSAL DENSITY DESIGN ON MIX DURABILITY

It has been shown that asphaltic surfacings must retain a minimum of 3 per cent VIM after trafficking to prevent plastic deformation. On severely loaded sites in tropical environments the final density of the surfacing is likely to be very close to refusal density. With a target level of compaction of 95 per cent of refusal density this implies that the air voids content of the surfacing material after compaction by road rollers may be in the region of 8 per cent (see AI MS2, 6th Edition). At this air voids content the surfacing will be very vulnerable to oxidation and ingress of water. Also whilst material in the wheel paths will be compacted by traffic other areas will tend to retain high air void contents. It is therefore essential that the surfacing is sealed at the time of construction.

The best method of preventing age hardening at the surface of a hot mix asphaltic layer is to apply a surface dressing at, or soon after, the time of construction. Although a single seal will give beneficial results, a double seal should ensure a long maintenance-free service-life. Such a layer has several beneficial characteristics:

(a) Only conventional materials and construction methods are involved.
(b) The method is relatively inexpensive and allows the use of deformation resistant binder course materials which are cheaper and more easily manufactured than dense AC wearing courses.
(c) The dressing inhibits asphalt hardening in the underlying hot mix layer by providing a very thick film of asphalt at the road surface.
(d) The dressing is very durable, flexible and resistant to cracking.
(e) The dressing will provide good texture for improved skid resistance.

An alternative surfacing is a 'Cape seal' which consists of a slurry seal placed on a single surface dressing. However, because the composition of a slurry seal is similar to AC, it is similarly prone to asphalt hardening and must be designed with great care if a durable and textured surface is to be obtained.

9. CONCLUSIONS

1. Asphaltic surfacings recently constructed in Kenya have been very prone to plastic deformation. Large percentages of the materials laid on several sites have had air void contents, at the time of construction, which were too low to allow for secondary compaction under traffic. This has resulted in the surfacings in the wheel-paths becoming overfilled with asphalt and then deforming plastically.
2. There is considerable evidence to suggest that asphaltic wearing courses on heavily trafficked roads in Kenya must be designed to retain a minimum of 3 per cent VIM after secondary compaction by traffic. This is in agreement with the results of work carried out elsewhere by TRL, and the recommendations of the Asphalt Institute.
3. It is probable that recent changes in vehicle characteristics, and the increasing use of radial ply tires, have produced a more aggressive loading regime which has played a significant part in the failure of asphaltic surfacings through plastic deformation.
4. In order to allow for severe secondary compaction at the mix design stage it is necessary to increase the level of compaction used in the design process. The results have shown that compaction to refusal can provide a reliable reference density against which the ultimate characteristics of the mix can be compared.
5. A new test procedure, using an electric vibrating hammer, has been described. This procedure will ensure that the volumetric design of mixes which must be resistant to plastic deformation under severe traffic loading conditions can be successfully carried out.
6. Whilst performance testing of design mixes is the ultimate goal, the proposed methodology and inexpensive equipment should help to prevent many premature surfacing failures in emerging countries where only the basic Marshall test equipment is available.
7. Asphaltic mixes designed for severe traffic loading conditions in tropical climates must be sealed to prevent premature 'top down' cracking associated with age hardening of the asphalt in the surface of the layer.

10. ACKNOWLEDGMENTS

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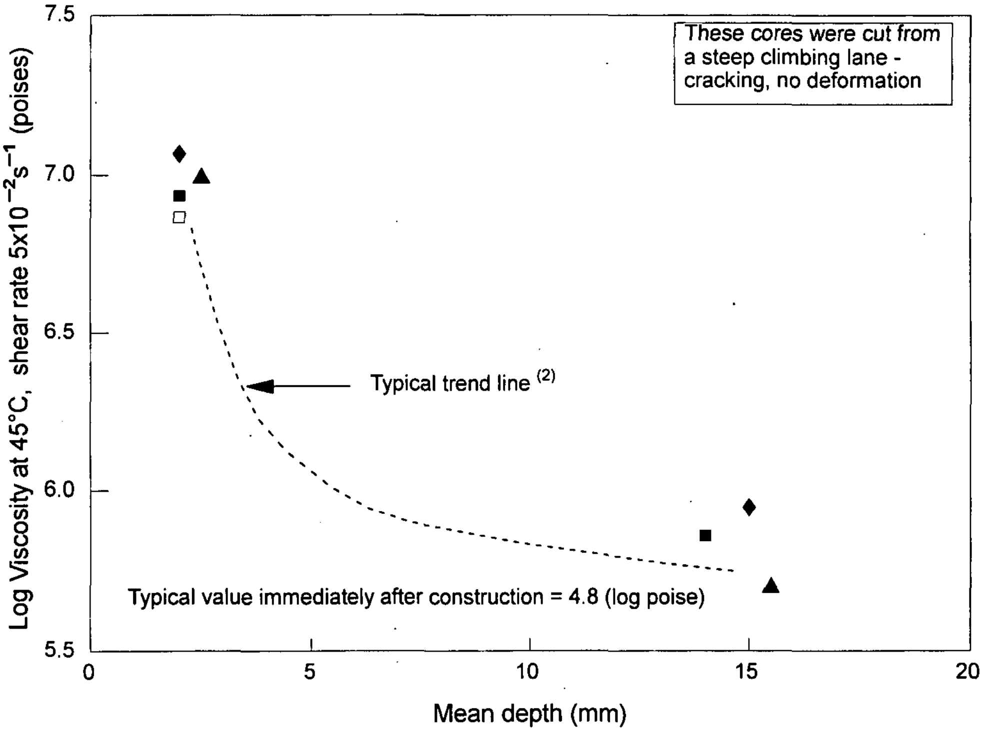

Figure 1 Viscosity of bitumen recovered from AC at Kangocho

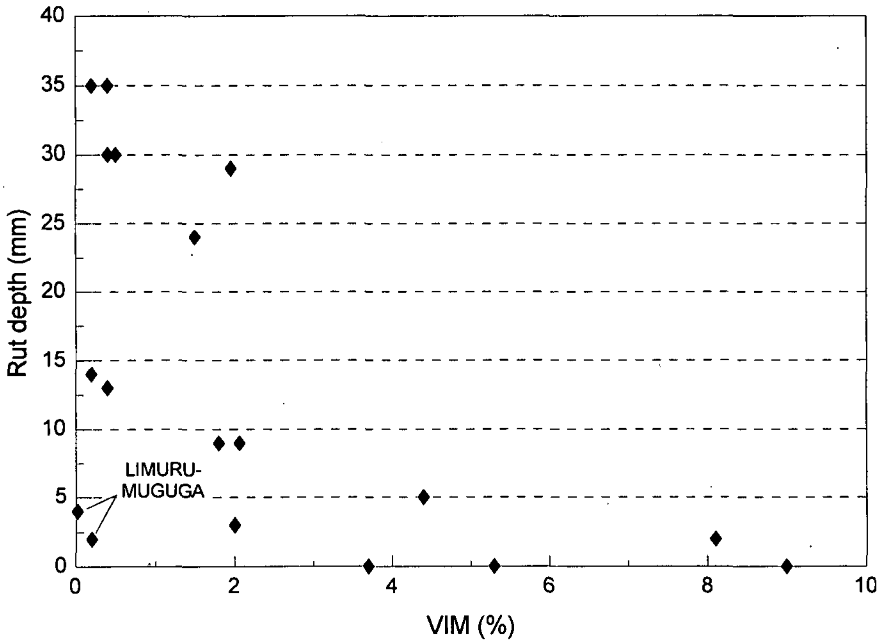

Figure 2 Relationship between VIM and rut depth

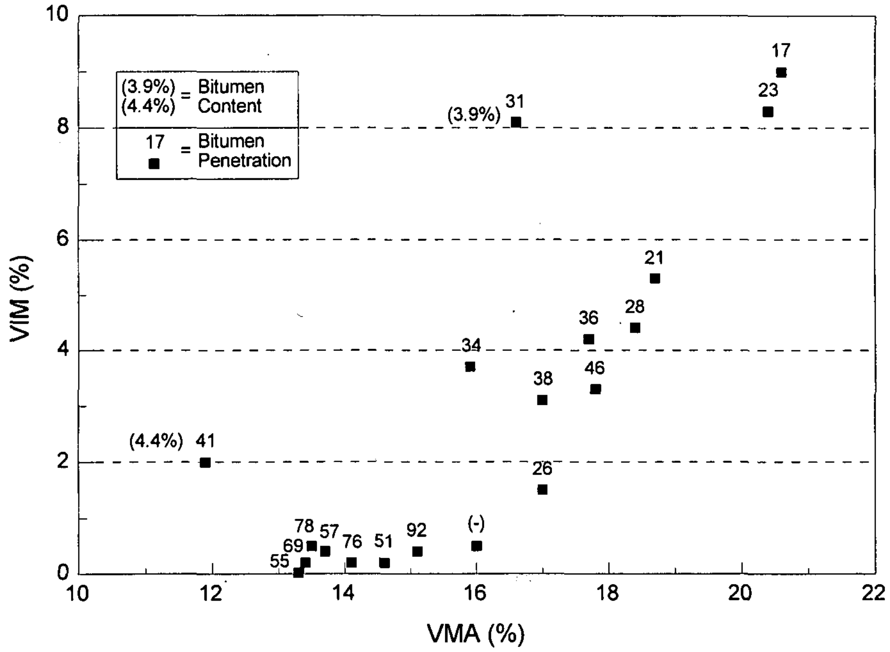

Figure 3 Relationship between VIM and VMA in core samples

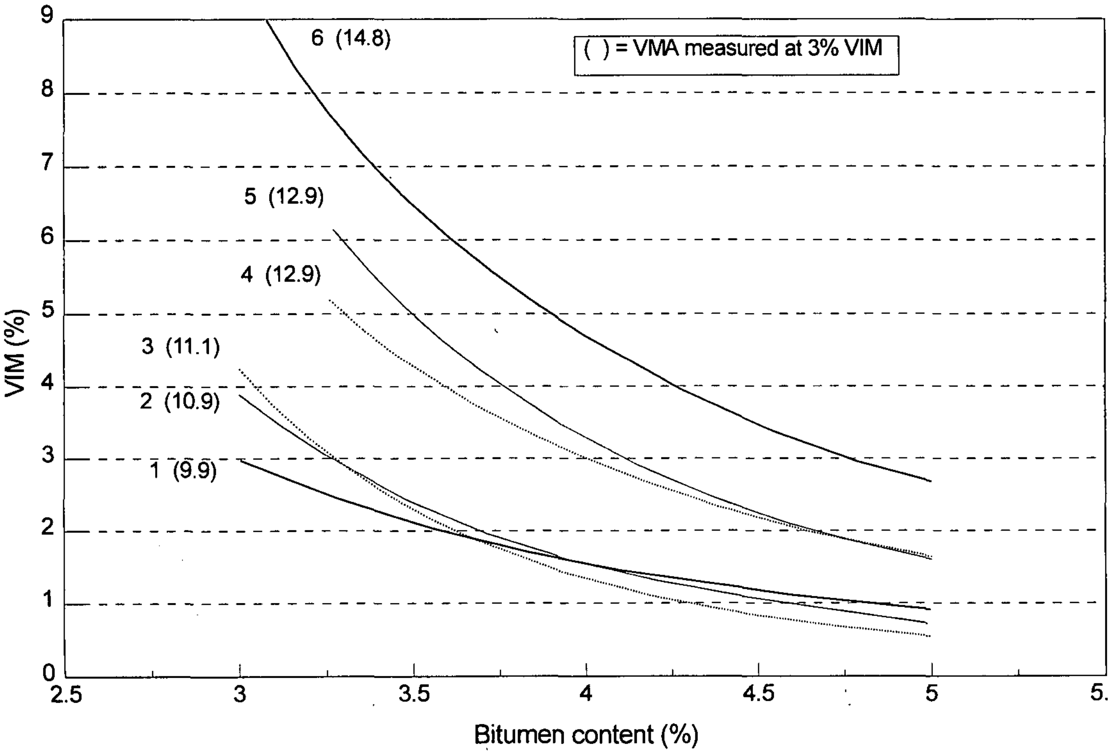

Figure 4 Vibratory hammer compaction of mixes using UK aggregate

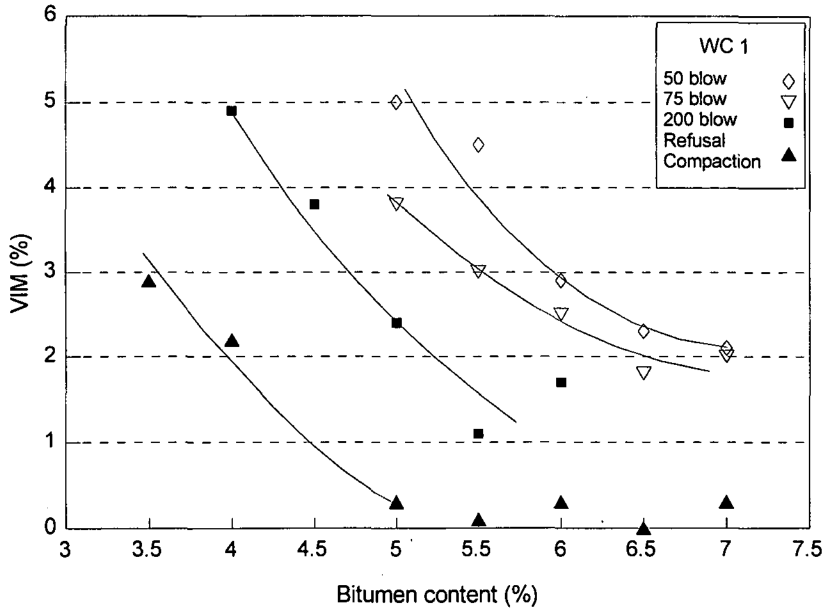

Figure 5 Relationship between bitumen content and VIM for different levels of compaction of wearing course mix

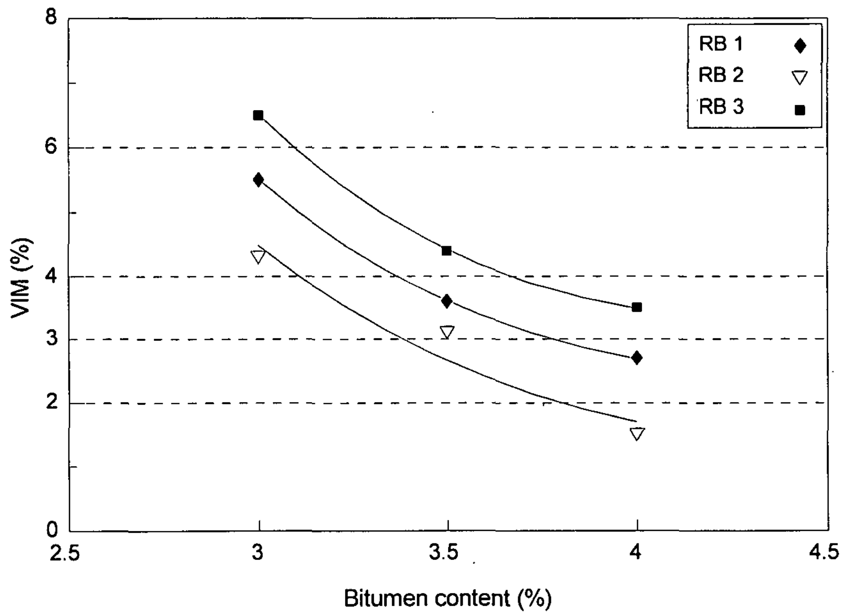

Figure 6 Relationship between bitumen content and VIM for refusal compaction of roadbase mixes