

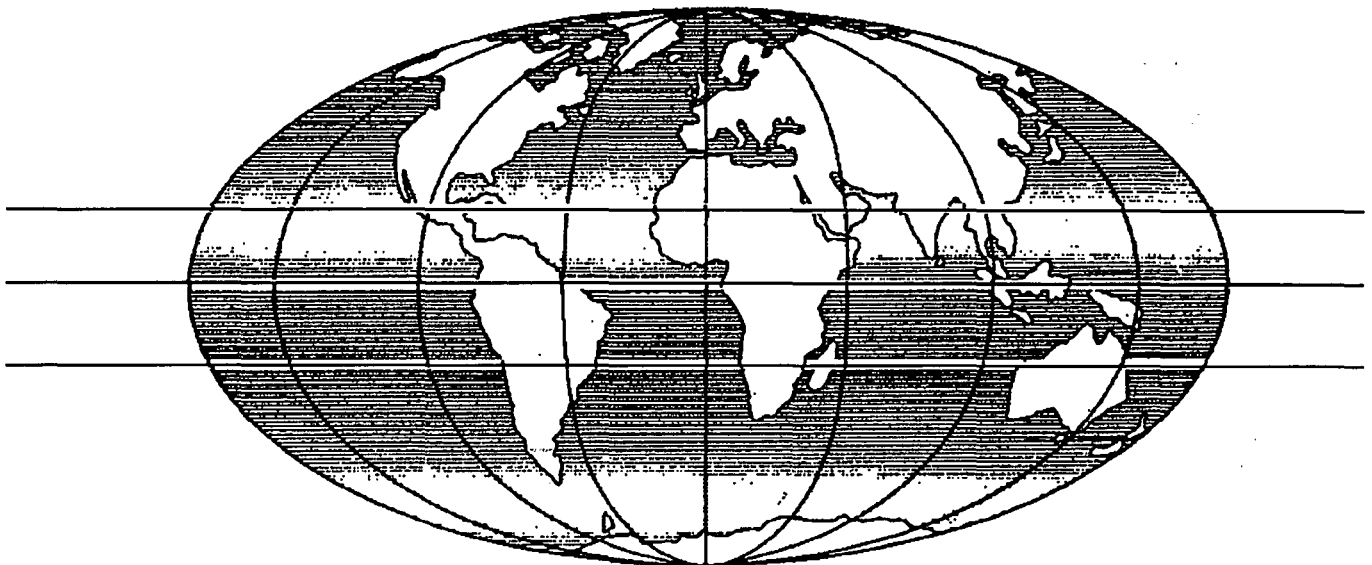


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TITLE Durability of bituminous overlays and wearing courses

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SMITH, H R, J ROLT and J WAMBURA, 1990. The durability of bituminous overlays and wearing courses in tropical environments. In: Proceedings of Third International Conference on Bearing Capacity of Roads and Airfields, Trondheim, Norway, 3-5 July 1990. Trondheim: The Norwegian Institute of Technology.



Third International Conference on
**BEARING CAPACITY OF ROADS
AND AIRFIELDS**

3-5 July 1990
TRONHEIM, NORWAY

THE DURABILITY OF BITUMINOUS OVERLAYS AND WEARING
COURSES IN TROPICAL ENVIRONMENTS

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ABSTRACT

This paper describes an investigation into the durability of a range of asphalt wearing courses and overlays on the main road network of Kenya together with the results of a much wider range of mixes prepared in the laboratory. The results show that large increases in bitumen viscosity occur quite rapidly in the top few millimeters of all asphalt surfaces. Where air voids were interconnected bitumen hardening occurred throughout the layer and relationships were derived between bitumen viscosity, age and mix properties. However for all mixes large increases in viscosity occurred in the top 3 millimeters. For this thin surface layer, age was the dominant factor. The mix properties were statistically significant but only of second order. The application of a surface dressing to the premix layer was found to be the most successful method of reducing the rate of age hardening in the surface of the asphalt and preventing the formation of cracks. The complex nature of age-dependant effects and the changing susceptibility to cracking from traffic and temperature induced stresses makes the development of precise predictive 'life models' extremely difficult. However, for circumstances similar to those of the study experiments, knowledge of the critical degree of hardening at which cracking occurs and of the rate at which ageing takes place for the different surfacings will allow rational rehabilitation and maintenance strategies to be adopted.

1. INTRODUCTION

In recent years the occurrence of surface-initiated cracking in asphalt surfacings and overlays has been widely reported (Dauzats and Linder, 1982, Strauss et al, 1984). Rolt et al 1986, described the performance of several types of asphalt overlays placed on a variety of road structures in different climatic areas within the Republic of Kenya. Severe hardening of the binder at the surface of the overlays and widespread surface-initiated cracking occurred. This cracking did

not correlate with the usual assessments of pavement strength or traffic loading and the prediction of overlay 'life' was not possible.

To investigate this behaviour further, a second cooperative study between the Kenya Ministry of Public Works and the Overseas Unit of the Transport and Road Research Laboratory was undertaken. It comprises a study of the effects of natural weathering on blocks of asphalt manufactured in the laboratory and five sets of full-scale trials.

The objectives of the study were:-

1. To further investigate factors influencing the performance of bituminous overlays in tropical environments and, in particular, the relationship between ageing and surface cracking.
2. To investigate factors affecting the ageing of bituminous mixes and methods of preventing or retarding this ageing.

2. THE EXPOSURE BLOCK STUDY

2.1 EXPERIMENTAL DESIGN

An important advantage of the block study, compared to full scale experiments, was that a wider range of mix variables could be included and accurate composition assured. The addition of a surface dressing was expected to reduce ageing in the underlying asphalt because of the additional volume of bitumen at the surface.

The grading used for asphaltic concrete (AC) was as specified in the Kenya MPW design manual (1981). Three grades of bitumen were used, 80/100 pen and 60/70 pen from the Kenya refinery and 40/50 pen from the Fawley refinery in England. Some of the blocks were surface dressed. Details of the mix variables are given in Table 1.

Air void contents for blocks in group 1 were in the range from less than one per cent to seven per cent. Surface dressed blocks had air voids between three and nine per cent and blocks in the remaining groups were between one and five per cent.

2.2 METHOD OF MANUFACTURING BLOCKS

Air voids content was controlled by sample weight and compacted height. The blocks were approximately 80mm high and 152mm in diameter. This size of specimen minimised edge effects and any minor errors in composition. Compactive effort was applied to each face of the sample with a vibrating hammer fixed vertically to the pillar of a coring machine. The specific gravity of the mix was determined using the method recommended by Rice (1953).

TABLE 1

Mix details for exposure blocks (Nairobi Aggregate)

GROUP No	BITUMEN CONTENT (PER CENT)	FILLER CONTENT (PER CENT)	NUMBER OF AIR-VOIDS VARIATIONS	PENETRATION GRADE OF BITUMEN
1	6.9	6.9	5	80/100
2	6.9	6.9	3	60/70
3	6.9	6.9	3	40/50
4	6.9	6.15	3	80/100
5	6.9	4.9	3	"
6	6.9	7.65	4	"
7	6.9	8.9	2	"
8	6.4	6.9	3	"
9	5.9	6.9	3	"
10	7.4	6.9	2	"
11	7.9	6.9	3	"
12	6.9*	6.9	4	"
13	6.9*	6.9	3	"

* Surface dressed with dark coloured aggregate.

** Surface dressed with white aggregate.

Blocks were placed in sand in 400mm square by 90mm high trays. Asphalt was compacted into the top 35mm of the trays to provide a free-draining surface with characteristics similar to those of the samples themselves and road surfacings. The relevant trays were surface dressed with MC 3000 cut-back bitumen applied at a rate of 1 litre per m² and 12mm chippings.

2.3 TESTING OF BLOCKS AND ROAD CORES

After the selected period of exposure the densities of road cores and blocks were measured in a gamma-ray scanning apparatus which measured the bulk specific gravity of 4mm thick sections throughout the depth of the samples. The top 3mm of each sample was sawn off and bitumen recovered from the slices in a rotary evaporator. Bitumen viscosity was measured in a sliding plate viscometer at a temperature of 45°C.

2.4 RESULTS OF EXPOSURE BLOCK STUDY

2.4.1 Hardening at the top of the blocks. Multiple regression techniques were used to quantify the effects of age and mix variables on the rate of hardening of the bitumen in the top 3mm of 170 blocks made with 80-100 penetration grade bitumen (see Table 1, groups 4-11). The models are summarised in Table 2. Model 3 in the table is illustrated in Figure 1.

TABLE 2

Relationship between viscosity, age and block properties

(Top 3mm, Nairobi aggregate and 80-100 pen bitumen)

MODEL No	REGRESSION COEFFICIENTS FOR MODELS WITH DEPENDENT VARIABLE OF LOG ₁₀ VISCOSITY (45°C, POISE)					r ²
	CONSTANT	LOG ₁₀ AGE (MONTHS)	PER CENT			
			AIR VOIDS	BITUMEN	FILLER	
1	4.673 (46.23)	1.989 (21.83)	-	-	-	0.74
2	4.285 (38.54)	2.050 (24.67)	0.082 (6.15)	-	-	0.79
3	5.032 (15.66)	2.043 (24.94)	0.068 (4.81)	-0.099 (2.47)	-	0.79
4	5.867 (20.39)	1.994 (23.05)	-	-0.173 (4.40)	-	0.76
5	6.230 (18.91)	1.994 (23.31)	-	-0.173 (4.44)	-0.054 (2.19)	0.77
6	5.319 (14.32)	2.040 (25.00)	0.065 (4.51)	-0.103 (2.57)	-0.036 (1.53)	0.79

Student's 't' values are given in brackets

The increases in viscosity are strongly related to age but are practically independent of air voids. These results are typical of those obtained for all blocks which were not surface dressed.

The results show that, after 24 months, bitumen viscosity in the top 3mm increased by a factor in the range 200-500. The mix variables of air voids, bitumen content and filler content were significant but of only second order, affecting viscosity by factors of between 1 and 3 over the range of the variables studied. Indeed 74 per cent of the variation in viscosity was explained by the age variable alone, inclusion of the other variables increased the explained variation by only 5 per cent (Table 2).

2.4.2 Effect of bitumen grade. The age-viscosity relationships for the 80-100, 60-70 and 40-50 penetration grade bitumens became indistinguishable after 24

months exposure indicating that, in the long term, the grade of bitumen is relatively unimportant as far as ageing is concerned.

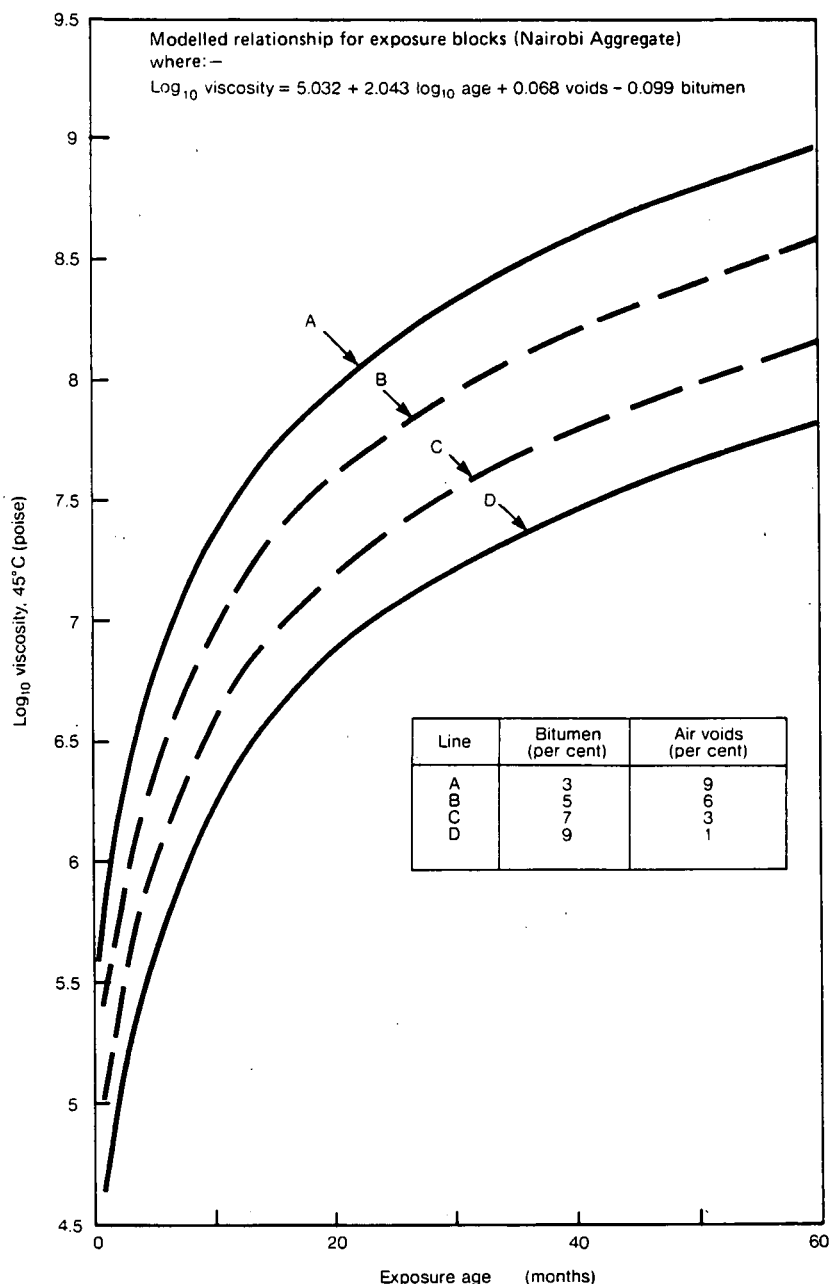


Fig. 1 Modelled relationships between bitumen viscosity and mix parameters for top 3mm of exposure blocks

2.4.3 Hardening within the blocks. A proportion of the blocks were sliced horizontally and the bitumen in each slice tested to determine the viscosity depth profiles. Some profiles are illustrated in Figure 2 together with those obtained from the nearby full scale trials at Ruaraka which experienced the same climatic conditions. Similar viscosity gradients developed but, after 24 months hardening within the blocks was some ten times higher than in the road.

2.4.4 The effect of surface dressing. The surface dressing was removed before the top 3mm of the blocks were sliced for testing. The light and dark coloured aggregates produced a difference in temperatures at the top of the bitumen film of

between 4 and 6°C on bright sunny days but this does not appear to have had a significant effect on the degree of hardening in the underlying premix.

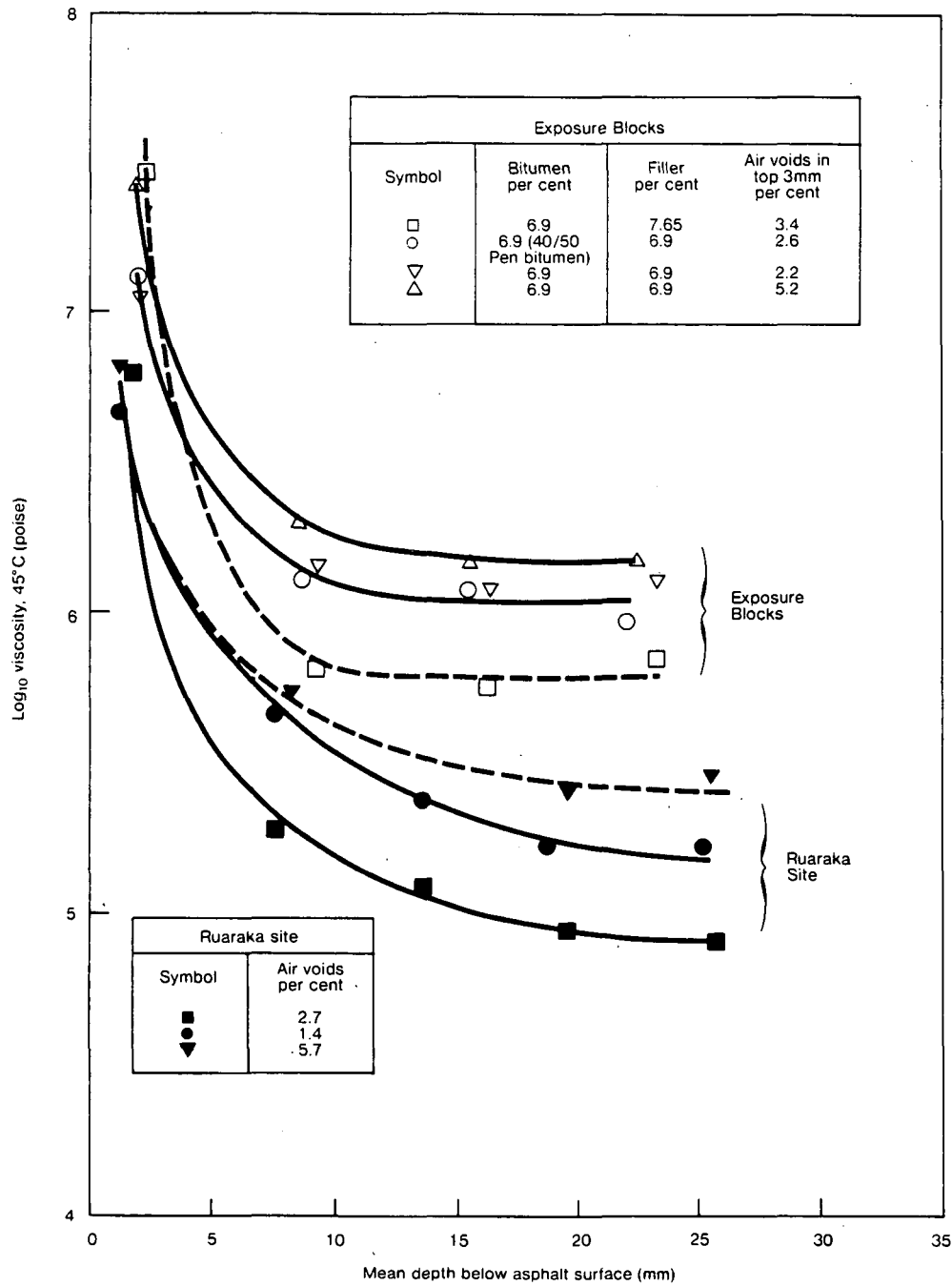


Fig.2 Change in bitumen viscosity with depth after 24 months exposure

The regression model obtained for the viscosity of the bitumen in the 3mm of the premix underneath the surface dressing was:-

$$\text{Log}_{10}\text{Visc.} = 4.304 + 0.9221\text{Log}_{10}\text{ Age} + 0.043\text{AV} \quad (2.1)$$

where Age = Age in months

AV = Air voids, per cent

The r² value for this model was 0.86. All the surface dressed blocks were made at

one bitumen content and therefore this term does not appear in the model.

The results show that hardening in the top 3mm of the premix after 24 months exposure is about fifty times less by virtue of the surface dressing, the coefficient in the model being reduced from 2.05 (Model 2 in Table 2) to 0.92. Air void content had little effect on hardening, changing the degree of hardening after 12 months exposure by no more than a factor of two at the extremes compared with factors of ten or more because of age.

2.4.5 Hardening of the surface dressing. The viscosity of bitumen recovered from surface dressing on 24 month old blocks was 4 times higher than in the underlying 3mm of asphalt but some twelve times less than the top 3mm in unsealed blocks.

3. THE FULL SCALE ROAD TRIALS

3.1 DESIGN OF THE EXPERIMENTS

Three groups of structural overlays and two groups of surfacings on reconstructed pavements were laid on principal trunk roads in Kenya. Details of the sites and the experimental variations are summarised in Table 3.

TABLE 3

Details of site and material variations

SITE NAME	NUMBER OF SECTIONS	ALTITUDE AND ENVIRONMENT	TYPE OF CONSTRUCTION	VARIATIONS INCLUDED
PALA	5	1400m Hot, wet	Cape seal on DBM overlays	Thickness
KISUMU	3	1200m Hot, wet	AC wearing course on re-construction	Bitumen content
UPLANDS	10	2100m Relatively cool seasonally wet	Surface-dressed DBM and AC on DBM overlays	Thickness. Bitumen content.
THIKA ROAD	8	1500m Intermediate temperature seasonally wet	AC overlays	Bitumen content. Pre-coated chippings
RUARAKA	4	As for Thika road	AC wearing course on re-construction	Bitumen content. Pre-coated chippings

The local geography at Uplands appears to cause a higher incidence of cloud cover over the site than at the others. This together with the higher altitude causes an average difference of approximately 8°C in mean monthly minimum and maximum temperatures between this site and that at Thika road.

AC wearing courses have a limited capacity for bitumen above which instability and poor surface texture become serious problems. Variations of bitumen content were in the range from 0.3 per cent below to 1.0 per cent above Marshall optimum. Pre-coated chippings were supplied at a rate of 8kg per m² to some of the 'normal' and 'rich' AC mixes to improve surface texture and to examine the effect of increased stone content at the surface on the rate of hardening. Dense bitumen macadams (DBM) are similar to AC, but usually have a more open grading and higher air void content; they can therefore accept more bitumen if required and have slightly more tolerance to batching errors than AC.

It was anticipated that because of practical limits on mixing tolerances, changes in mix design would not be sufficient to overcome the problems of rapid ageing and hardening of the bitumen. It has been shown that the top few millimetres of a surfacing harden much more severely than the rest of the layer and therefore overall improvements in performance should be obtained by reducing the ageing of this layer. The study therefore included an examination of the effectiveness of cape seals and surface dressings as protective layers. These seals are relatively thin but can provide a thick bitumen film which should be resistant to oxidation without increasing the risk of deformation under traffic. Furthermore the strain developed in thick films should be much lower than in the thin films found in premixes and therefore a greater degree of hardening should be tolerable before fracture occurs. For both of these reasons, thin, flexible, bitumen rich surfaces are expected to perform well.

A total of 30 different sections were constructed over the five sites, with the length of each section ranging from 50 metres, for those with precoated chippings, to 200 metres. Performance monitoring has now been underway for up to 74 months.

3.2 BEHAVIOUR OF THE OVERLAYS AND WEARING COURSES

All of the overlaid sites were structurally sound. Overlay thicknesses were between 120 and 240mm and deflection-curvature measurements indicated that little structural damage would be expected to occur for many years. The most likely failures were expected to be deformation in the bitumen-rich mixes. In fact, within 2 years, many of the unsealed AC's developed fine cracks at the surface.

3.3 RESULTS OF THE FULL SCALE TRIALS

The hardening of the bituminous materials has been looked at in three ways:

- a) general hardening of the complete layers of DBM or AC basecourses under seals and also AC wearing courses.
- b) hardening of the top 3mm of AC layers.
- c) hardening of surface seals.

It has not been possible to derive a comprehensive model to explain the behaviour across all sites because of the large number of variables involved, especially the site specific variables such as altitude, cloud cover, ambient temperature, traffic and rainfall. However, Table 4 is a general summary of the results illustrating the ranges of the various effects and the levels of improvement obtained with the different treatments and the different designs.

TABLE 4

Mean viscosity of recovered bitumen after
24 months exposure (Log_{10} , Poise at 45°C)

Material origin	Environment	
	Mild (1)	Severe (2)
DBM base course layer under seals	5.98	6.25
AC base course layer under wearing courses	-	6.32
Surface dressing (on DBM)	6.20	-
Cape Seal (on DBM)	-	6.50
Top 3mm 'rich' AC	6.00	6.46
normal AC	6.18	6.80

- 1) Uplands site.
- 2) Thika road, Ruaraka and Kisumu sites.

The viscosities summarised in Table 4 all show considerable increases from the 'as laid' values which had a mean of 5.38 (Log_{10} poise at 45°C) and a range of 5.20-5.68. After ageing the range of the results was similar, lying between plus or minus 0.3 of the mean values quoted in the Table.

3.3.1 Sealed DBM and AC basecourses and asphalt surfacings. The results in Table 4 show that , under a seal and in the 'mild' environment of the Uplands site, the viscosity of bitumen recovered from DBM layers increased by a factor of approximately 4 in 24 months. In the harsher environment of Pala the viscosity increased by a factor of 7. Despite the protection of 50mm of AC wearing course, bitumen in the AC basecourse at Kisumu hardened by a factor of 11 in 24 months. These basecourse mixes have void contents in excess of 6 per cent. It appears that hardening throughout the depth of the layer is inevitable in tropical environments, regardless of the type of cover.

3.3.2 Cape seal and surface dressings. The viscosity of bitumen in the cape seal at the time of construction would have been considerably lower than that of bitumen in new asphalt. Nevertheless, after 24 months it was 13 times greater than the mean value for bitumen in new asphalt. However, the bitumen content was such that the majority of the surface developed a 'live' appearance. After 24 months the surface dressings at Uplands, constructed with MC 3000 cut back bitumen, had hardened to 7 times the mean value for bitumen in new asphalt. This surface developed a rich appearance whilst retaining good surface texture.

3.3.3 Asphaltic concrete. Few of the samples cut from the road sites had air voids contents above the normally permitted maximum value of 5 per cent (at the time of construction) and the majority were below the recommended minimum value of 3 per cent. All of the asphalt mixes, irrespective of bitumen content, developed viscosity-depth profiles similar to those shown in Figure 2. Increases in the viscosity of bitumen recovered from the top 3mm of bitumen rich mixes after 24 months, ranged from four times the as laid values at Uplands to twelve times in the more severe climatic conditions at Thika road. Comparative increases for the conventional AC's were six times at Uplands to 26 times at the Kisumu site.

The rich mix at Uplands behaved in a similar way to the other sections of AC surfacing, developing a thin hard layer at the surface. There would have been a serious risk of deformation if heavy traffic had used the road. At Thika Road the rich asphalt deformed by 7mm after 30 months trafficking. Little texture was retained on these sections.

3.3.4 Precoated chippings. Surface texture is reduced to unacceptable values in most AC surfacings and is particularly poor in 'rich' mixes. The addition of precoated chippings has been very effective in providing good, long term, texture in such mixes. However, no reduction in the rate of bitumen hardening could be detected.

4. DISCUSSION OF RESULTS

4.1 EXPOSURE BLOCKS

Air voids had little effect on the viscosity of bitumen recovered from the top 3mm of exposure blocks. Severe surface hardening occurred even in samples which had been compacted to refusal. It therefore seems unlikely that the ageing of the top few millimetres of the blocks is influenced by air voids.

Age-viscosity relationships for 80-100, 60-70 and 40-50 penetration grade bitumens converged after some 24 months exposure. In practice it may be beneficial to use a hard bitumen, compatible with operational requirements, because the asphalt would retain more of its original design characteristics. Use of 60-70 penetration bitumen is probably the best compromise.

Bitumen hardening was reduced under a surface dressing with a bitumen film thickness of approximately 1mm. In a normal surface dressing the film thickness would be approximately half of the average least dimension of the stone chippings and therefore be considerably thicker than 1mm. A surface dressing applied to an AC surfacing at the time of construction should therefore be even more effective than that applied to the exposure blocks.

A comparison of the rates of bitumen ageing in blocks and road samples is given in Figure 3. Ageing effects in the blocks were more severe than for asphalts in the road. In the absence of traffic the surface of the blocks developed a 'dry' appearance unlike the road surfacings which had a more bitumen-rich and 'live' appearance. However the trends in terms of bitumen hardening in relation to mix properties were similar.

4.2 CHANGES IN BITUMEN HARDNESS IN ROAD ASPHALTS

The results indicate that environmentally induced changes in asphalt properties with time are large and are likely to be the dominant factor in determining overlay life in countries with tropical climates.

Bitumen hardening in the surface of normal asphalt layers in the Kenyan environment, and probably in most tropical countries, is inevitable unless more durable bitumens can be manufactured. It is essential that these changes in asphalt properties are fully considered as part of the overlay design process. It is clear that overlay materials can develop different moduli throughout their depth and their fatigue and deformation properties changes significantly with time (Rolt et al, 1986).

The incorporation of additional bitumen into asphalt mixes with low air voids is unlikely to prevent hardening in the surface of the mix whilst the risk of poor

surface texture and deformation occurring under traffic is unacceptably increased. Even bitumen in a 'rich' area of a cape seal which had 'veins' of free bitumen in the surface had hardened to 26 times the as laid value of asphalt after 74 months.

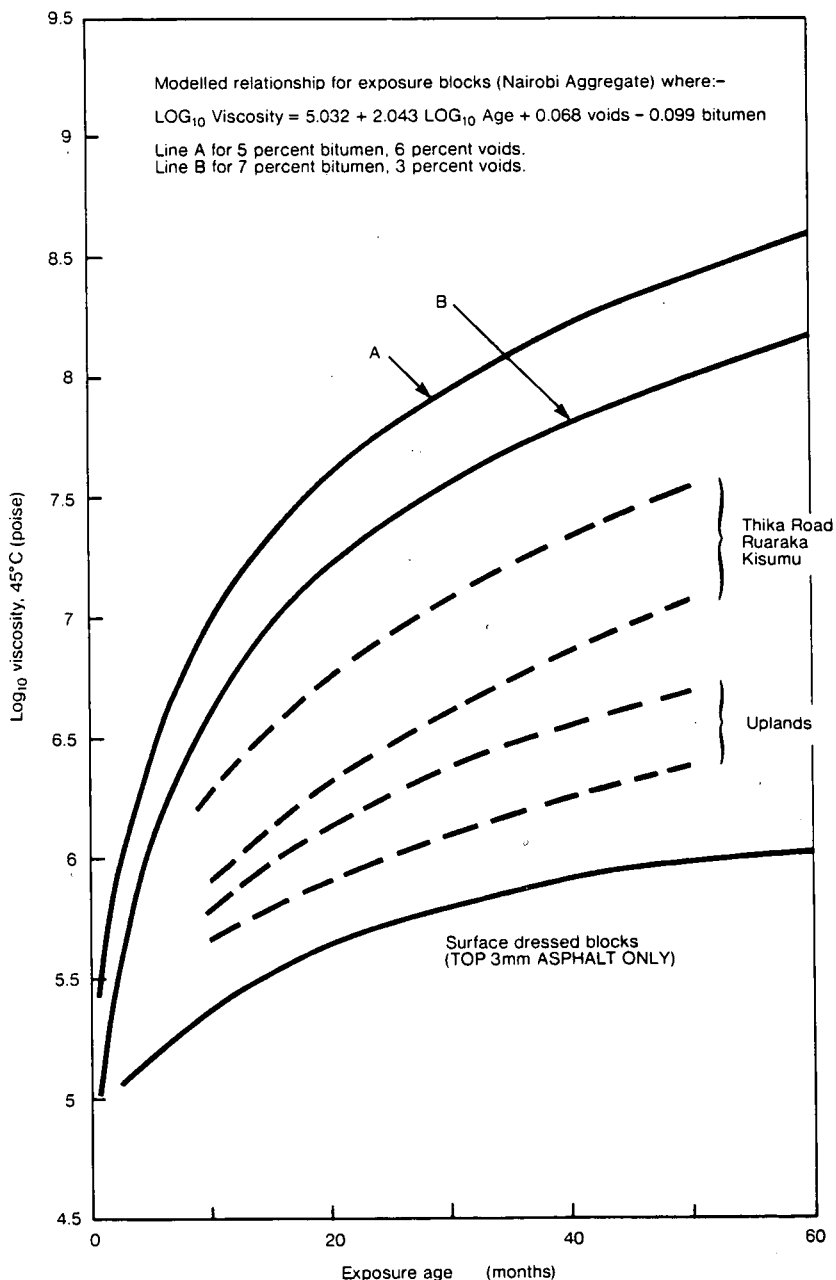


Fig.3 Relationships between bitumen viscosity and age for the top 3mm of exposure blocks and AC road samples

Slurry seals can be durable but specialist equipment, design and construction methods are required. The design problems are similar to those for asphalt. Great care is needed to achieve a balance between a durable product, which retains surface texture, and one that is liable to fretting.

Surface dressing has been shown to be very effective in preventing extreme bitumen hardening at the surface of asphalt, and therefore of reducing the risk of surface initiated cracking.

There are considerable advantages in placing a surface dressing on a new asphalt

surfacing:-

1. The rate of bitumen hardening at the surface is significantly reduced.
2. Current technology and materials can be used immediately.
3. Conventional asphalt can be laid for which resistance to deformation has not been compromised in an attempt to improve ageing properties.
4. Because of the thicker film of bitumen present in a surface dressing the strain capacity to fracture within the bitumen will be greater than in an AC or DBM which has hardened to a similar degree.
5. Safety will be improved by the enhanced surface texture.

5. CONCLUSIONS

The major conclusions from the research project described in this paper are as follows:-

5.1 In the Kenyan environment, severe bitumen hardening occurs at the surface of AC wearing courses. This results in a brittle skin which is prone to early surface initiated cracking. Such cracking does not correlate with the usual assessments of structural strength or traffic loading.

5.2 Bitumen hardening occurred at the surface of dense mixes with very low air voids and higher than normal bitumen contents. A marked viscosity gradient developed in the top 10mm of the asphalt.

5.3 Exposure time was the dominant factor in determining the degree of bitumen hardening in the top 3mm of dense AC surfacings. Bitumen, voids and filler contents had a statistically significant but small effect upon the rate of hardening.

5.4 In a highland area, where the pavement temperature was some 8°C lower, the rate of hardening was approximately one third of that in the hotter environment.

5.5 After two years exposure there was little difference in the viscosities of bitumens recovered from blocks made in the laboratory with 80-100, 60-70 and 40-50 penetration grade bitumens.

5.6 Surface dressings were very effective in reducing bitumen hardening in the top 3mm of asphalt blocks. The viscosity of the recovered bitumen was 10 times less, at 24 months, than in nearby road samples and 70 times less than in unsealed blocks.

5.7 Increasing the bitumen content, in an attempt to reduce the rate of hardening, resulted in surfacings at risk of deformation under traffic, very poor surface texture and little reduction in the rate of hardening.

5.8 Pre-coated chippings, rolled into the surface of bitumen-rich surfacings during construction, dramatically improved surface texture but had little effect upon the rate of bitumen hardening at the top of the surfacing.

5.9 DBM overlays sealed with a surface dressing or a cape-seal have proved to

be very effective in resisting deformation and surface-initiated cracking.

5.10 The complex nature of age-dependent effects on bituminous material properties and the changing susceptibility to cracking from traffic and temperature induced stresses makes the development of precise predictive 'life models' extremely difficult.

6. ACKNOWLEDGEMENTS

The authors are indebted to the Government of the Republic of Kenya for constructing the experiments and for the help and cooperation given at all phases of the study.

The work described in this paper forms part of the research programme of the Overseas Unit (Unit Head: Mr J S Yerrell) of the Transport and Road Research Laboratory, carried out on behalf of the Overseas Development Administration. Any views expressed are not necessarily those of the Administration or of the Department of Transport. The paper is published by permission of the Director of the Laboratory. Crown Copyright. Extracts from the text may be reproduced, except for commercial purposes, provided the source is acknowledged.

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