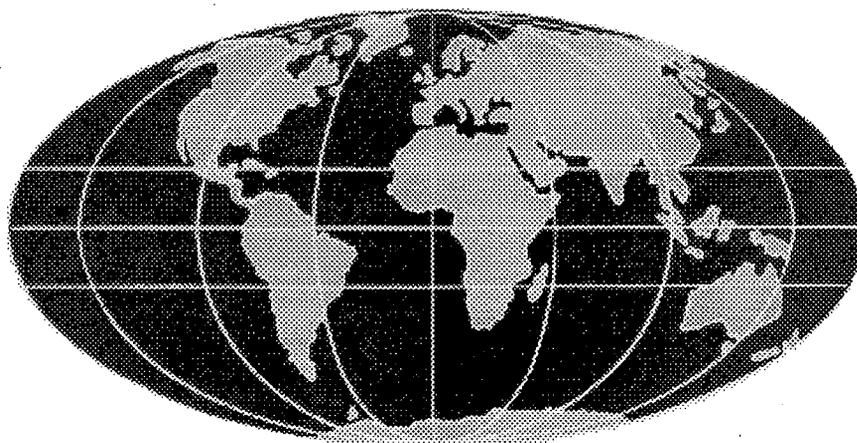


**TITLE: Top-Down Cracking: Myth or
Reality?**

by: J Rolt



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TOP-DOWN CRACKING: MYTH OR REALITY ?

1 SYNOPSIS

In the late 1970s and early 1980's most highway engineers did not believe that top-down cracking occurred at all or, if they did, they thought that it was a relatively rare event that did not warrant serious attention. This paper describes research that led TRL to believe that the problem was much more serious than engineers had perceived. The paper begins with a summary of a large full-scale pavement design experiment in the tropics that in which the roads did not display the kind of structural behaviour that was expected. It explains how top-down cracking was recognised and describes the associated factors that seemed to determine its characteristics. At the same time, TRL engineers began to look for evidence of top-down cracking throughout the world and discovered that not only did it seem to be widespread in tropical environments, but there was also considerable evidence of its common occurrence in more temperate climates such as France and Holland. The study identified the most probable cause of the problem and was followed by another experimental study of the behaviour of a range of asphalt mixes with the objective of finding a practical way of either preventing the problem from occurring or mitigating its adverse effects. The paper concludes with ideas for solving the cracking problem. Some of the possible solutions give rise to a high risk of deformation failures in asphalt materials and therefore both

problems need to be solved simultaneously. This is dealt with in the paper by Harry Smith later in this conference.

2 THE FIRST ASPHALT PERFORMANCE STUDY

The first asphalt study took place as long ago as 1973-1977 (Rolt J, H R Smith and C R Jones, 1986). Its original objective was to produce a design guide for strengthening roads by means of asphalt overlays for use in tropical environments. The research procedure adopted was to construct a series of full-scale experimental trials in which the key variables were controlled. A total of 64 overlays were constructed on eight different sites, thereby covering a considerable range of climatic conditions from hot, humid coastal areas, through semi-arid areas, to high altitude, high rainfall, cooler areas. The overlays were laid on a variety of road types covering a range of strengths, as measured by deflection values, and traffic levels. The overlay thicknesses ranged from 30 to 170mm and the thicknesses on each site were selected to bracket the design thickness obtained from the UK thickness design method that was in use at that time. The overlays themselves consisted of a variety of different mix designs including four different types of asphaltic concrete, two types of hot rolled asphalt (a gap-graded mix much used in the UK) and a traditional dense bitumen macadam. It should also be noted that the experimented sections were laid as part of normal contracts and were constructed by different consultants and different contractors.

2.1 Performance monitoring

The degree of rutting, amount of cracking and deflections were measured regularly and a large number of cores were cut to study how the cracks had formed. Early in the study it was found that all the cracks started at the top of the overlay and propagated downwards, as shown in Figure 1. This type of deterioration was also reported in France (Dauzats M and R Linder, 1982), the Netherlands (Pronk A C and R Buiters, 1982) and South Africa (Hugo et al, 1982; and Strauss et al, 1984)). This is quite opposite to the expected behaviour. The critical stress is generally thought to be the radial stress at the lower side of the premix layer. Cracks should therefore begin at the lower surface of this layer and propagate upwards.

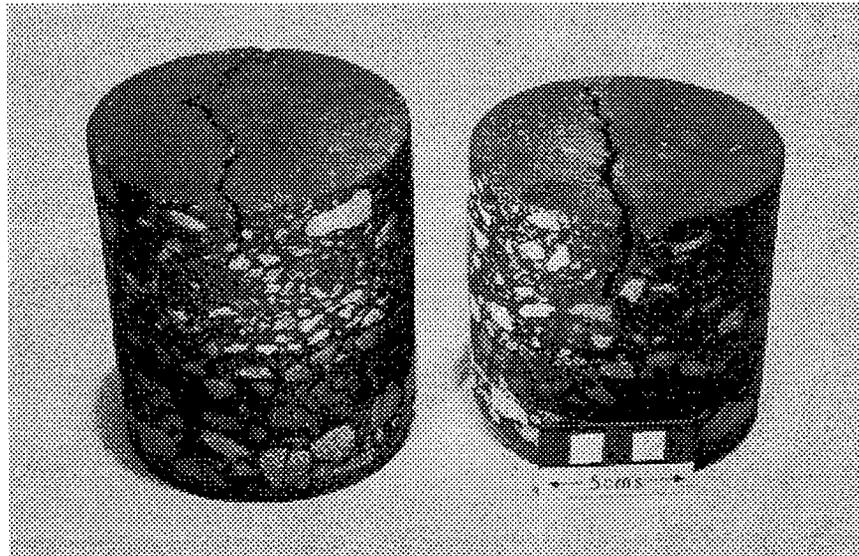


Figure 1 Cores showing top-down cracking

Initially it was suspected that the visible cracks might merely be the top part of cracks that extended right through the asphalt layer but with the lower part of the crack being very fine and invisible to the naked eye. However, the nature of the cracks indicated that this was unlikely since the cracks were typically a millimetre or more wide with a very rounded crack tip. Indeed, later information indicated that the cracks often seemed to remain at a constant depth for some time before finally propagating to full depth. Samples of overlay were taken periodically to measure the properties of the recovered bitumen. It was found that rapid age hardening occurred on most of the experimental sections with the notable exception of five sections which were very rich in bitumen as a result of a construction error. This is illustrated in Figure 2 where the viscosity of bitumen recovered from thin 2-3 mm layers is shown as a function of depth.

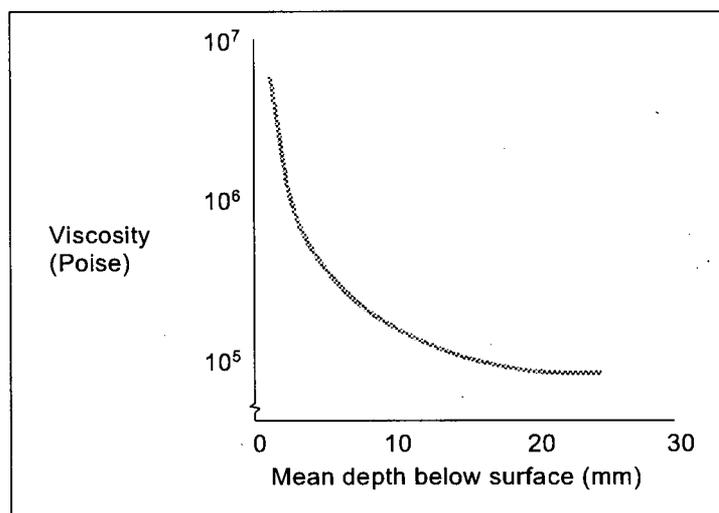


Figure 2 Viscosity of recovered bitumen with depth

The bitumen in the top 2-3 mm of the surface layers is over 100 times more viscous, and hence stiffer and more brittle, than the bitumen in the centre of the layers.

2.2 Performance of the overlays

Most of the experimental sections were constructed on relatively heavily trafficked roads including four sites on different sections of a main intra-continental route on which the traffic in one direction of travel, in terms of equivalent standard axles, was three times more than the other. Despite this large difference, the degree of cracking on both side of the road was practically identical. Detailed analysis of all the data collected during the course of the study showed that the performance of the overlays could not be related to any of the normal structural variables that one would expect to control performance. Thus the behaviour of the overlays did not depend significantly on traffic, deflection (before or after applying the overlays) or overlay thickness.

The behaviour depended to a certain extent on the characteristics of the mixes themselves such as binder content, voids in the mix, filler/binder ratios and so on, but the exact relationships were difficult to determine.

The age hardening of the asphalt was clearly a key component in the cracking mechanism. Nevertheless, although 75 per cent of the

mixes that age-hardened during the study period of eight years cracked progressively and extensively, there remained about 25 per cent that did not crack, giving important clues for understanding how to prevent cracking.

3 THE SECOND ASPHALT PERFORMANCE STUDY

The second asphalt study was designed to provide a much better understanding of the relationship between the ageing of the bitumen and the compositional properties of the mixes. At the same time, several methods of reducing the degree of age hardening were investigated and a further set of full-scale trials were constructed (Smith, H R, J Rolt, and J Wambura, 1990).

To investigate the ageing, blocks of asphalt were manufactured in the laboratory and then exposed to natural weathering on the roof of the Ministry building. An important aspect of this 'block' study (in comparison to full-scale trials) was that a much wider range of the values of the mix variables could be included and accurate composition of the mixes could be assured. Details of the composition of the blocks is shown in Table 1. The bitumen was obtained from two different sources to allow any potential problems with bitumen quality to be identified. It should be noted that some blocks were coated with a surface dressing.

Table 1 Composition of the asphalt blocks

VARIABLE	No. of VARIATIONS	COMMENTS
Grade of bitumen	3	40/50, 60/70, 80/100 pen
Bitumen content	5	5.9 – 79 %
Filler/binder ratio	5	0.7 – 1.3
Air voids	5	1.0 – 9.0 %
Aggregate type	2	

Note some blocks were surface dressed.

After manufacture, the blocks were placed in sand boxes and an asphalt surface was provided to simulate a normal field environment (Figure 3).

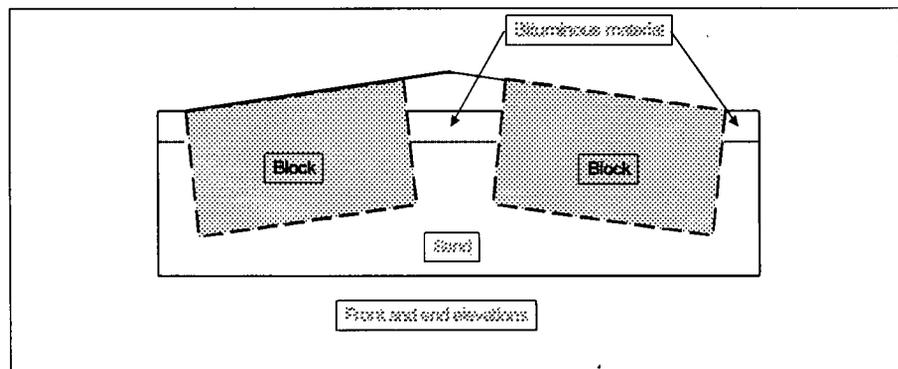


Figure 3 Blocks of asphalt in sand boxes for exposure study

After selected periods of exposure, blocks were tested in a number of ways. First a gamma-ray scanner was used to measure the

density of the blocks as a function of depth and then the samples were sawn horizontally to provide layers of about 3 mm thickness. The bitumen was recovered from these layers and its viscosity measured in a sliding plate viscometer.

3.1 Results of the 'exposure blocks' study

Multiple regression techniques were used to quantify the effects of age and mix variables on the hardening of the bitumen *in the top 3mm* of the samples. Two typical models are:-

$$\text{Log}_{10}(\text{VISC}) = 5.03 + 0.43 * \text{Log}_{10}(\text{AGE}) + 0.068 * (\text{VOIDS}) - 0.01 * (\text{BIT})$$

Where	AGE	=	age in months
	VOIDS	=	air void in percent
	VISC	=	viscosity measured in Poise in a sliding plate viscometer at 45°C
	BIT	=	bitumen content in per cent

Figure 4 illustrates the models that were derived. The results show that, after 24 months, bitumen viscosity in the top 3mm increased by a factor in the range 200-500. This increase in viscosity is strongly related to age but the mix variables of air voids, bitumen content and filler content, although significant, were only of second order, affecting viscosity by factors of between 1 and 3 over the range of the variables studied. These results are typical of those obtained for all blocks which were not surface dressed. 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

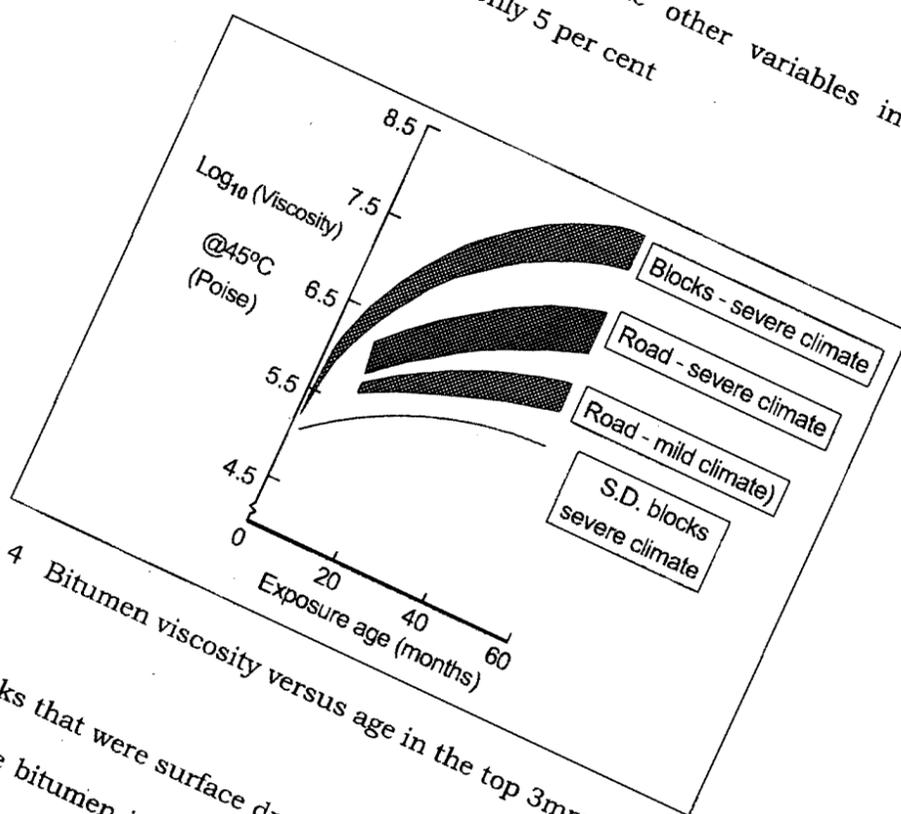


Figure 4 Bitumen viscosity versus age in the top 3mm of surface

For the blocks that were surface dressed the following equation was derived for the bitumen in the top 3mm of the asphalt layer under the surface dressing:-

$$\text{Log}_{10}(\text{VISC}) = 4.3 + 0.92 \cdot \text{Log}_{10}(\text{AGE}) + 0.043 \cdot (\text{VOIDS})$$

The effect of the surface dressing was to reduce the level of ageing in the top of the asphalt mix by a factor of 50 after 24 months. This is also shown in Fig 4. The bitumen in the surface dressing also hardened but at a rate that was an order of magnitude less than in the top 3 mm of the unsealed blocks.

The age-viscosity relationships for the 80-100, 60-70 and 40-50 penetration grade bitumens became indistinguishable after 24 months of exposure indicating that, in the long-term, the grade of bitumen is relatively unimportant as far as ageing is concerned

3.2 The full-scale trials

A total of 32 test sections were constructed to investigate methods of reducing the age hardening. Details are shown in Table 2.

Table 2 Details of full-scale trials

Site	No of sections	Altitude and Environment	Type of construction	Variables studied
1	5	1400m; hot wet	Cape seal on DBM overlays	Thickness
2	3	1200m; hot wet	AC wearing course on reconstruction	Bitumen content
3	10	2100m; cool, seasonally wet	Surface dressing on DBM and AC overlays	Thickness and bitumen content
4	8	1500m; intermediate temperature, seasonally wet	AC overlays	Bitumen content, effect of pre-coated chippings
5	4	1500m; intermediate temperature, seasonally wet	AC wearing course on reconstruction	Bitumen content, effect of pre-coated chippings

AC wearing courses have a limited capacity for extra 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.

It was anticipated that because of practical limits on mix composition, changes in mix design would not be sufficient to overcome the problems of rapid ageing and hardening of 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 of bitumen should be much lower than in the thin bitumen 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 were expected to perform well.

3.3 Results of the full-scale trials

Overlay thicknesses were between 120 and 240mm and deflection measurements indicated that little structural damage would be expected to occur for many years. The most likely early failures were expected to be deformation in the bitumen-rich mixes. However, within 2 years, many of the unsealed asphaltic concrete surfaces had developed cracks at the surface.

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 3 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. The results indicate that age hardening in the real road was much less severe than for the 'exposure blocks' but that severe hardening is almost certain to occur with traditional materials and methods of construction.

In a supplementary study, the effect of ageing on the fatigue properties of asphalt mixes was examined. Fatigue tests can only be carried out on relatively large samples and so the degree of ageing that could be achieved with such samples was very much less than the degree of ageing in the top 3 mm of the experimental

Table 3
The relative degree of hardening (measured in terms of viscosity) compared with the as-laid material

Material	Environment	
	Mild	Severe
DBM base course layer under seals	4x	8x
AC base course layer		8x
Surface dressing (on DBM)	6x	
Cape Seal (on DBM)		12x
Top 3mm of bitumen 'rich' AC	4x	12x
Top 3mm of normal AC	6x	26x

The 'as-laid' value had a mean viscosity of 2.4×10^5 Poise at 45°C

overlays. Nevertheless, the dramatic decrease in fatigue performance at the higher strain levels is apparent in Figure 5 and the brittle nature of the changes that have taken place is clear.

4 CONCLUDING COMMENTARY

In tropical environments, severe bitumen hardening occurs at the surface of asphalt wearing courses. This results in the formation of a brittle skin that is prone to early top-down cracking. The occurrence of such cracking is not strongly related to the usual structural strength parameters or traffic loading.

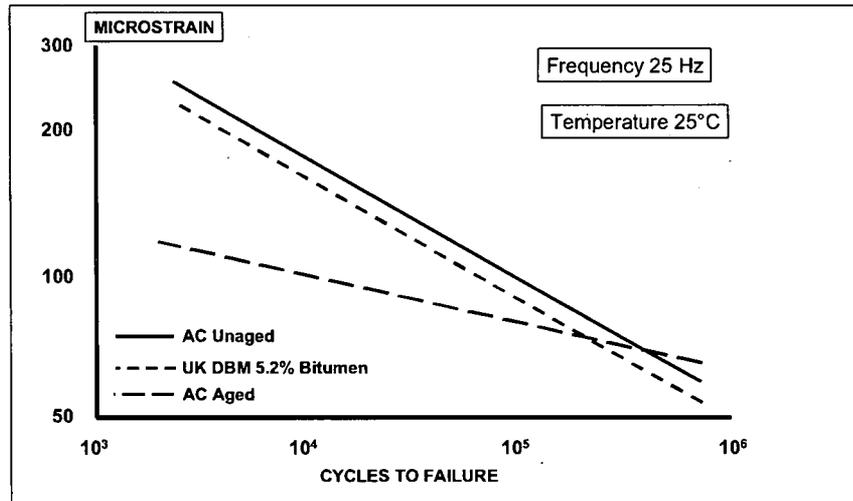


Figure 5 Fatigue properties of aged asphalt

Exposure time is the dominant factor in determining the degree of bitumen hardening in the top 3mm of asphalt surfacings. Bitumen content, voids and filler content had a statistically significant but small effect upon the rate of hardening.

The hardening is strongly dependent on ambient temperature. In a region where the pavement temperature was 8°C lower, the rate of hardening was approximately one third of that in the hotter environment.

From a study of the natural ageing of asphalt samples prepared in the laboratory, there is a strong indication that under hot tropical conditions there is little difference in the viscosity of 80/100, 60/70 and 40/50 penetration grade bitumens after two years exposure.

Thus there may be little advantage to be gained by using softer binders as far as ageing is concerned.

Surface dressing is very effective at reducing the hardening of bitumen in the top 3 mm of the underlying asphalt surfaces and therefore in reducing the risk of top-down cracking. In the 'block' study, after 24 months exposure the viscosity of the recovered bitumen was 10 times less than in nearby road samples and 70 times less than in unsealed blocks. There are, therefore, considerable advantages in placing a surface dressing on an asphalt surfacing. These are

- The rate of bitumen hardening at the surface is significantly reduced.
- Current technology and materials can be used immediately.
- There is no need to jeopardise the deformation resistance of conventional asphalt by adjusting the mix composition in an attempt to improve its ageing properties .
- Because of the thicker and more continuous film of bitumen that is present in a surface dressing, the strain capacity before fracture of the bitumen is greater than in an AC or DBM which has hardened to a similar degree.
- Safety will be improved by the enhanced surface texture.

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.

The complex nature of the age-dependent properties of bituminous materials and the changing susceptibility to cracking from traffic and temperature induced stresses makes the development of predictive models very difficult.

5 ACKNOWLEDGEMENTS

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