RECOMMENDATIONS ON THE USE OF MODIFIED BINDERS TO RETARD REFLECTIVE CRACKING

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Abstract

Recommendations on the application of modified bituminous binders on cracked pavements are made. Field and laboratory results from various research projects are combined in a prediction model of surfacing performance under specific conditions. The purpose is to make it easier for practitioners to properly design surface treatments to retard the reflection of active cracks. The model is meant to be an aid to practitioners in parallel with existing design methods.

1   INTRODUCTION

The limited funds available for the maintenance of the South African road network demand more cost-effective use of available resources. Changes in the physical characteristics of available binders necessitate the modification of existing test methods for materials . New design methods are sometimes called for where new materials are used in applications requiring the input of more relevant information. Where modified binders are used to retard the reflection of active cracks through surface treatments, this is particularly true. Previously, the level of crack activity was not known. Methods of measuring crack activities have become available and this information needs to be provided for in design methods.

Over a period of about ten years, the CSIR and BKS Inc. conducted research into the problem of reflection cracking. Recommendations are made for the rehabilitation of roads with active cracks. The work is done for the Department of Transport, the Southern African Bitumen and Tar Association (SABITA) and various other clients. The projects included laboratory work (fatigue evaluation of binders under simulated crack movement) and field work (construction and evaluation of field sections) (Strauss and Jordaan, 1) (Rust et al, 2).

To date, these projects have generated several outputs. These include the Crack Activity Meter (CAM) (Rust, 3) (Coetser, 4), the Crack Movement Simulator (CMS) and

fatigue curves for various modified binders in which the effects of temperature, binder application rate, ageing of the binder and loading waveform and frequency are taken into consideration. A prediction model of fatigue performance of modified bituminous binders in single seal surface treatments has been developed, based on the performance of binders on trial sections (Coetser, 5). Finite element analyses have been performed, resulting in a prediction model for the reflection of cracks through overlays.

2   CRACK SEALING METHODS

Several methods are currently used to seal cracks in road pavements. These vary in design, the materials used, method of construction and application. They all have one common denominator: bituminous binders.

2.1   Surface treatments

Surface treatments are usually applied on roads where cracking of the existing pavement is too extensive for hand sealing of individual cracks, or where skid resistance of the road surface needs to be improved over long distances. Several methods are available, including single seals, double seals, Cape seals, sand seals, slurries, etc. All, except slurries, consist of the application of a bituminous binder, followed by layers of single sized stone. Very often, more than one layer of binder is applied. Surface treatments normally cover the full width of a road. Several design methods are being used by the various road authorities.

2.2   Crack filling

This method consists of the sealing of individual cracks. It is a very labour intensive operation. For fairly small areas or widely spread cracks it can normally be used effectively. However, on areas where extensive cracking occurs over long distances, it can become very time-consuming and expensive. Cracks should be carefully prepared. Very often these methods fail within a few months, although they can be very successful. Failure occurs where any separation of the sealant from the pavement material occurs, or where the sealant tears and thus opens channels for surface water to penetrate the pavement.

2.3   Geosynthetics

Geosynthetic "blankets" are sometimes used to cover surface cracks. The material is normally impregnated in some way with a bituminous binder. Occasionally, where skid resistance is a factor, surface treatments are added. It can only be used cost-effectively to cover individual cracks. It becomes very costly to treat large areas in this way. During the past few years, some work has been done on low-volume roads where mechanical methods were used to apply the material to a road.

3   MODIFIED BINDERS IN SURFACE TREATMENTS

Several modified bituminous binders have entered the market since the early eighties. These binders can be effective in retarding reflective cracks on account of their

improved rheological and elastic properties. When used in asphalts, they possess properties which make them good materials to consider under abnormal loading or environmental conditions.

3.1   Types of modifiers

Several types of modifiers can be used to modify the normal production type bituminous binders. In South Africa, four modifiers are generally used. These are Styrene Butadiene Rubber (SBR), Ethylene Vinyl Acetate (EVA), crumbed rubber and Styrene Butadiene Styrene (SBS).

SBR is an elastomeric polymer which is blended with bitumen, usually B4 (150/200 pen) and B8 (80/100 pen) road grade bitumens, at temperatures in the region of 160 °C. The result is a homogeneous binder with improved elasticity. For seal applications, the modifier is usually added at percentages of between 2 % and 5 % by mass of the modified binder. Bitumens should be selected with care to ensure proper compatibility with the modifier. Bitumen emulsions can also be modified with SBR. Two methods of producing modified emulsions are used. With the first method, the bitumen is modified before emulsification. With the second method, the emulsion itself is modified. Modification is usually done to have 5 % SBR by mass of the residual bitumen.

EVA is a plastomeric polymer. It is used in a solid form and is also blended with road grade bitumens at high temperature.

Rubber crumbs, which are derived from the grinding of truck and car tyres at ambient temperature, are blended with bitumen at high temperature. The result is a heterogeneous bitumen-rubber blend with very high elasticity. It can be used very successfully in surfacing seals, hand sealing and in asphalts. Because of its high elasticity, it is very resistant to the reflection of active cracks.

Styrene Butadiene Styrene (SBS) is currently being used on an experimental basis in South Africa. It is also an elastomeric polymer, but exhibits better elastic properties than SBR. Both bitumens and bitumen emulsions can be modified with SBS and the resulting binders are used in both surface treatments and asphalts.

3.2   Laboratory testing

There are several prescribed properties of modified binders and test methods to be used. Because of the changes in the base bitumens and modifiers available on the market, these test methods need to be updated from time to time. At the time this report was written, the SABITA Modified Binders Task Group was reviewing interim technical guidelines (SABITA, 6) for homogeneous modified binders in seals. SABITA Manual 3 contains specifications for test methods for bitumen-rubbers used in seals (SABITA, 7). Bitumen-rubbers and the materials to be used to prepare this binder are described in SABITA Manual 4 (SABITA, 8). These are continuously under revision. A serious shortcoming of these specifications is that they do not properly address the problem of reflection cracking.
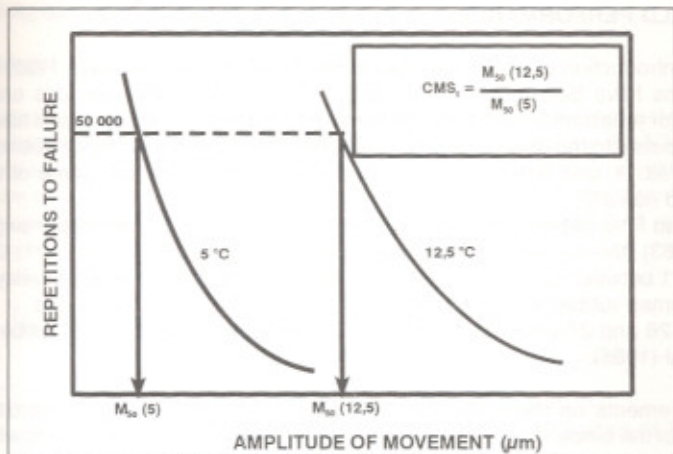
3.2.1 Physical properties

The interim specifications for homogeneous modified bitumens are given in Table 1 (SABITA, 6).

Table 1: Interim specifications for hot-applied modified bitumens

Property	Generic type of modified bitumen				
	Plastomer	Elastomer polymer			
	EVA	SBR	SBS	SBR	SBS
Base bitumen	150/200 pen (B4)	150/200 pen (B4)		80/100 pen (B8)	
Softening point (R&B) ASTM D36 (°C)	48 min	45 min	47 min	47 min	49min
Dynamic viscosity at 135 °C (Brookfield) ASTM D4402 (dPa.s)	5,0 min	5,0 min	5,0 min	10,0 min	10,0 min
Ductility at 10 °C (mm) ASTM D113	300 min	1000 min	500 min	1000 min	500 min
Elastic recovery by means of ductilometer at 10 °C (%)	45 min	55 min	60 min	55 min	60 min
Stability (R&B diff. °C)	2 max	2 max	2 max	2 max	2 max
% Adhesion at 5 °C 10 °C	90 - 100 100	90 - 100 100		90 - 100 100	

3.2.2 Simulated crack-movement

None of the prescribed tests fully measures the ability of a binder to retard reflective cracking. The Crack Movement Simulator (CMS) (Coetser, 4) test is used to determine the ability of a binder to withstand repetitive movement of cracks under controlled conditions. The standard conditions in the CMS test are:

- temperature   modified binders: 5 °C or 12,5 °C
                              unmodified binders: 12,5 °C
- loading frequency   5 Hz
- loading function   sinusoidal
- rest periods   none
- simulated crack width 1 mm
- sample thickness   2,5 mm
- direction of movement horizontal
- controlled strain mode

In order to compare the fatigue performances of binders in the CMS test three values can be determined from the fatigue curves. The first value is called the M_{50}-value. It is the amplitude of movement on the CMS (in µm) at which the binder lasts for 50 000 repetitions before failing (see Figure 1). It is normally measured at 5 °C.

Figure 1: Determination of M_{50}.

The second value (CMS_t) gives an indication of the temperature sensitivity of a binder. It is the ratio between M_{50} at 12,5 °C and that at 5 °C.

$$CMS_t = \frac{M_{50}(5)}{M_{50}(12,5)}$$

.... (Eq. 1)

The third value (CMS_P) gives an indication of the performance of a binder in the CMS test at any combination of test conditions (eg temperature, amplitude of movement, loading frequency, etc.) The result is a number which gives an indication of the performance of the material. The numbers are usually between 1,0 and 4,0, the higher number indicating better performance in terms of retarding reflective cracks. In order to compare the performances of various binders, the test conditions should be the same for all the binders. The following formula is used to calculate CMS_P:

$$CMS_P = \log\left(\frac{L}{t} \times \epsilon\right)$$

.... (Eq. 2)

where: L   =   repetitions to crack appearance.
         t   =   film thickness at crack (mm), and
         ε   =   amplitude of movement (mm).

3.2.3   Correlation between test methods.

The M_{50}-values of the modified binders used in the N3 trials (Coetser, 5) were correlated with a variety of rheological properties by means of linear regression analyses and the only correlations of significance were those between M_{50} and tenacity (INSTRON) and between M_{50} and tenacity (ductilometer). None of the results from other tests had any significant correlation with results from the CMS test. It is clear that the normal tests cannot indicate the ability of a binder to resist reflective cracking.

4   FIELD PERFORMANCE

Since the introduction of bitumen-rubber to the South African market in 1982, several trial sections have been planned, designed and built. All these sections are being monitored for reflection cracking and performance in general and the results have been used as inputs into the development of the performance prediction model (Strauss and Van der Walt, 9, and Renshaw et al, 10). These sections include some of the first constructed namely:

- Road P1/6 between Pietersburg and Potgietersrus: bitumen-rubber single seal (1983) (the so-called "Ysterberg"-section);
- N2/1 between Somerset West and DF Malan airport: single seal interlayer plus bitumen-rubber asphalt (1983), also a major contract in 1985, and
- N2-26 and 27 between Umdloti and New Guelderland: bitumen-rubber single seal (1985).

Crack movements on these sections were measured and accurate records of the properties of the binders used were kept. This information, together with knowledge of traffic, allows one to develop models that enable the designer to predict performance.

Field sections were constructed on the slow traffic lane of the N3 highway south of Johannesburg in 1987 (Mac Carron and Rust, 11). This road is the main route between the Reef and Durban and is used by a large number of very heavy vehicles. A number of traffic counts were done before and after construction of the sections. Several modified binders were used in single seal surface treatments on a cracked wearing course and monitored over a period of almost six years. The cracks had been induced in the asphalt wearing course by concrete blocks installed in the pavement. These blocks were supported on rubber mats to allow them to move under traffic loads. Crack movements under standard axle loads were measured before construction and on various occasions during the life of the experiment. Samples of all the binders were taken during construction and yearly thereafter and submitted to several laboratory tests, including the CMS test.

In all cases the general performance of the binders in terms of stone retention was very good (Edler and Coetser, 12). The only loss of stone occurred on sections where sprayer problems occurred during construction and on the section containing the control 80/100 penetration grade bitumen. The modified binders performed well in terms of stone retention. Fattening (bleeding) occurred in the wheel path on the bitumen-rubber sections where binder application rates were in excess of 1,9 ℓ/m^2.

The sections were mainly monitored for the appearance of cracks on the surface. Visual inspections were performed regularly and cracks noted as they appeared. The appearance of cracks were noted together with the magnitude of crack movement measured at the specific position where it appeared. The traffic on the sections since construction to the time cracks appeared were calculated. After about five years accumulated traffic on the sections were in excess of 1,7 million E80s (equivalent standard 80 kN dual wheeled axles).

5   PREDICTION MODELS

5.1   Model based on field performance

Several multiple regression analyses were performed to determine the best correlation between laboratory results and field performance of the surfacings in the N3 trials. The number of variables in the analyses had to be limited to obtain the relevant degrees of freedom for the regression analysis. The only laboratory result which correlates well with field performance, is the M_{50}-value which is calculated from CMS results. The following prediction model was found:

$$L_f = C_1 \cdot \left(\frac{M_{50} \times t}{TCM} \right)^a + C_2$$

.... (Eq. 3)

Where:

- L_f = predicted field life (E80s to failure);
- M_{50} = binder fatigue obtained from CMS testing at 5 °C (µm);
- t   = binder application rate (ℓ/m^2), and
- TCM   = total crack movement (µm).
- a, C_1, C_2 are constants

The calculation of TCM is performed by means of equation 4 and the process is described in detail elsewhere (Rust et al, 2). It is sufficient to say that TCM is a mathematical combination of differential horizontal and differential vertical crack movement as measured with the CAM. On flexible pavements the influence line of total movement often follows that of the horizontal movement. In these cases the differential horizontal crack movement from CAM measurements could be used as representative of the total movement.

$$TCM = \sqrt{(x + \delta x)^2 + (y + \delta y)^2} - \sqrt{(x^2 + y^2)}$$

.... (Eq. 4)

Where:

- x   = crack width (mm);
- y   = difference in block levels (mm);
- δx = change in crack width (mm), and
- δy = change in differential block level (mm).

The model is shown graphically in Figure 2 (Rust et al, 2).

The model as it stands has some limitations. Results from the field trials represent the climatic influences of only the area in which they were constructed. With care, however, the model can be used to include other factors in the prediction. The CMS-test can take into account the effects of ageing, varying crack widths, varying loading frequencies, etc. in order to simulate specific climatic and traffic conditions. For example, it has been found that, by increasing the loading frequency (which corresponds to traffic speed) of the CMS-test, some binders are influenced more than others. It was found that fatigue performance of a SBR-modified road bitumen was affected far more than that of a bitumen-rubber under the same conditions when the loading frequency was increased. Certain adjustments can thus be made to other allow for the environmental conditions of different areas and thereby to a certain extent
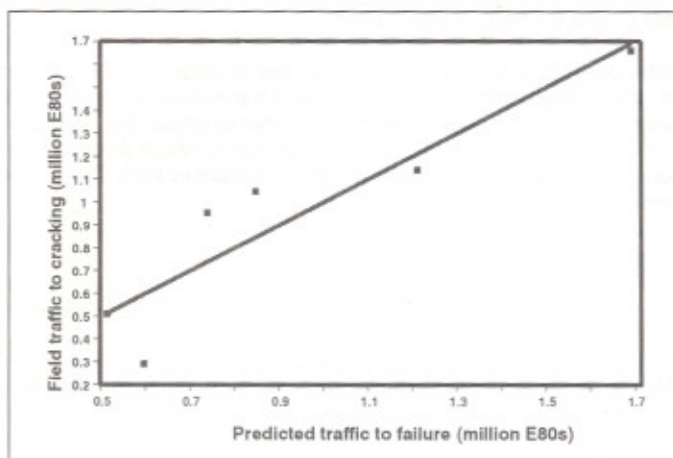
overcoming the limitations of the model.

Figure 2: Correlation between field performance and laboratory prediction.

5.2 Finite element analysis

Finite element modelling allows one to extrapolate beyond limited physical laboratory and field experience. Thus the relative influence of crack width, crack movement, stiffness of the material at different temperatures and with age as well as the thickness of the seal, can be determined. Results from this study can be used to compile a performance prediction model and a similar approach can be used to evaluate the merits of widening cracks, presealing before overlaying and the influence of crack pattern on reflection cracking. The results of this approach will be an equation similar in format to equation 3 above:

$$L_f = C_3 \times \left(\frac{t}{TCM} \right)^b \times \left(\frac{K}{S} \right)^c - C_4$$

$$\text{...} \quad \text{(Eq. 5)}$$

Where:

- L_f = predicted field life (E80s to failure);
- t = binder application rate (ℓ/m^2);
- TCM = total crack movement from CAM measurements (μm);
- K = crack width (mm), and
- S = stiffness of binder used as crack filler and binder used in seal.
- b, c, C_3, C_4 are constants

The implication of equation 5 is that as the binder stiffness changes with age or temperature, its affect on expected life can be determined. The same applies for crack width with the implication that widening of a crack contributes significantly to expected

life before reflected cracking access.

5.3 Nomograph of prediction model.

The model of equation 4, 5 was converted to graphical format to simplify its use. The nomograph is shown in Figure 3. The model can be used from either side. An example is given below.

Cracks were measured on a road using the CAM. The total crack movements were calculated and a representative value of 150 μm for a specific section determined. The consultant considers using a SBR-modified binder with an M_{50}-value of 100 μm at 5 °C. A typical binder application rate would be about 1,1 ℓ/m². These values are plotted on the nomograph as shown. The M_{50}-value is connected with the application rate by means of a straight line. This line is extended to line C-C. This point of intersection is connected with the total crack movement (150 μm, plotted on line D-D) and the line extended to intersect with line E-E. This gives an indication of the traffic, in this case just more than 700 000 E80s, which the treatment should be able to withstand before cracks reflect through the surface.

If the traffic figure is much lower than the estimated traffic which should use the road during the expected life of the surface treatment, other factors should be considered. One such factor is an increase in the binder application rate. The effect thereof on the possibility of fattening or bleeding should be evaluated by means of one of the available seal design methods. An alternative is to seal individual cracks before applying the surface treatment.

Another means of using the nomograph is, for example, to determine a possible binder to be used in a surface treatment. In this case the estimated traffic which should be provided for is plotted on line E-E. This point is then connected with the total crack movement on line D-D. From the intersection, a line is drawn to intersect with lines B-B and A-A. This line can be moved up and down to determine a suitable combination of binder and binder application rate. Once again it is necessary to evaluate the choice of binder and application rate by means of a standard seal design method in order to provide for good stone retention without the possibility of bleeding.

6 RECOMMENDATIONS

The recommendations given, pertain specifically to the use of modified binders in surface treatments where the primary aim is to retard the reflection of active cracks to the road surface. It is still necessary to do a proper design using existing design methods. The recommendations made in this paper should be seen as being additional to existing methods.

Where active cracks have reflected to the surface of a road, it is necessary to have knowledge of the magnitude of movement of these cracks before they can be properly treated. It is also necessary to know the different types of cracks and where they originate. As far as activity of cracks due to traffic loading is concerned, the most active, and most problematic, cracks are block cracks. These are formed in cemented base and subbase layers due to the shrinkage of cement and with time they progress

to the surface. As the blocks break down into smaller pieces, the activity of the cracks tend to increase. At a certain blocksize the activity tends to decrease again. At this stage the pavement is usually in a rather bad state with possibly other problems such as deformation, potholes, rutting, etc. It is important to make allowance for the increase in crack activity in order to prevent early failure of the surfacing in terms of reflection of cracks.

Cracks caused by movement of structural layers (eg. in mining areas) or due to traffic compaction are not always very active under traffic. In these cases measures other than only surfacings need to be considered. Modified binders in surface treatments are able to withstand the fast movements caused by traffic, but the larger, slow movements will soon cause failure of these materials.

Crocodile cracks are caused by the fatigue of aged binders in asphalts or by failure of the base materials. This type of failure should normally not be treated with a surface treatment. Other rehabilitative measures should be applied.

Crack activities can be grouped into specific categories. These categories are shown in Table 2 (Rust, 1). It should be noted that the classification is given in terms of total crack movement and not vertical or horizontal movement (refer to section 5.1). For each of the categories suggestions are made as to the most appropriate binder to be used in surfacings. It should be noted that other methods such as hand sealing and geotextiles have not been included in this table as the focus of this paper is on the use of modified bituminous binders in surface treatments.

Table 2: Classification of crack movement.

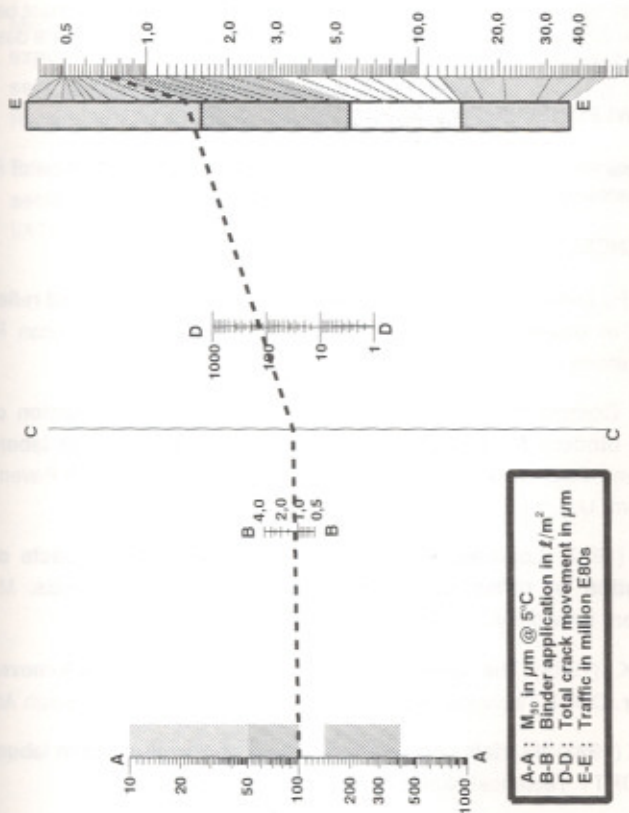| Crack movement	Classification	Suggested remedial treatment
< 0,1 mm	Low	Conventional surface treatments
0,1 to 0,2 mm	Medium	Surface treatment with homogeneous modified binder
0,2 to 0,3 mm	High	Surface treatment with bitumen-rubber
> 0,3 mm	Very high	Thick overlay (eg. SAMI)

Figure 3: Performance prediction model.

A-A : M₅₀ in μm @ 5°C
B-B : Binder application in ℓ/m²
D-D : Total crack movement in μm
E-E : Traffic in million E80s

7   CONCLUSIONS

The availability in recent years of new modified binders for use in road construction and rehabilitation required the modification of existing design methods. The performances of several trial surfacings containing modified binders are becoming available for use in determining performance-related design methods and criteria. Laboratory testing of the materials used in these trials in combination with field performance can be used to set up mathematical models for the prediction of field performance based upon certain inputs. Finite element analysis is a means of speeding up the process. It can take into account several factors, such as binder hardening through ageing and variations in crack width. These methods must be used as an aid together with existing design methods when surface treatments are designed to keep active cracks effectively sealed for acceptable periods.

8   ACKNOWLEDGEMENT

9   REFERENCES

1.   Strauss , PJ and Jordaan, GJ (1991) **Mechanistic design to avoid reflection cracking in overlays.** Research Report PR 88/214, South African Roads Board, Pretoria.

2.   Rust FC, Coetser K and Verhaeghe BMJA (1992) **The evaluation of six modified binders for retardation of crack reflection through laboratory studies and field work.** 7th International Conference on Asphalt Pavements, Nottingham, U.K.

3.   Rust FC (1987) **Load-associated crack movement and aspects of the rehabilitation of reflection cracking in cemented pavements.** M Eng dissertation, University of Pretoria, South Africa.

4.   Coetser K. (1989) **The Crack Activity Meter and the Crack-movement Simulator.** DRTT Technical Note I/PSB/53/89, CSIR, Pretoria, South Africa.

5.   Coetser K (1993) **N3 trials - correlation of field performance with laboratory results.** DRTT Technical Note I/AT/9/93, CSIR, Pretoria.

6.   SABITA Modified Binders Task Group. (1992) **Specifications, test methods and construction of seals using modified binders (homogeneous).** Draft: Technical guidelines

7.   SABITA. (1992) **Test methods for bitumen-rubbers used in seals.** Manual 3 Revised edition ISBN 0 620 11452 5.

8. SABITA. (1988) **Specification for rubber in binders**. Manual 4 ISBN 0 620 12364 8.

9. Strauss, PJ and Van der Walt, N (1989) **Stress absorbing membranes and flexible asphalt overlays to prevent reflection cracking at joints or cracks in stiff pavements**. CAPSA 89, Swaziland.

10. Renshaw, PJ, Strauss, PJ and Kleyn, EG (1989) **Review of the performance of a bitumen-rubber over a six year period**. CAPSA89, Swaziland.

11. Mac Carron CM and Rust FC. (1988) **The construction of a full-scale experiment to evaluate the effectiveness of various binders used in single seal surface treatments in retarding reflection cracking**. DRTT Research Report DPVT/185, CSIR, Pretoria, South Africa.

12. Edler AC and Coetser K. (1992) **Modified binders: N3 modified binder trial sections - condition five years after construction**. DRTT Technical Note I/AT/12/92, CSIR, Pretoria, South Africa.