This paper will review the experience gained from the use of bitumen (asphalt)-rubber in South Africa and states in Southern Africa (Swaziland and Botswana) over a 5 - 7 year period.

The Arm-R-Shield of Arizona Refining of Phoenix, Arizona, was first introduced to South Africa in October 1982, followed nine months later by a locally developed technology based on an Australian method. The Sahauro technology was introduced later. The main reason for the introduction of bitumen-rubber was to successfully deal with or entirely eliminate the problem of reflection cracking.

This paper will deal with the important issue of the correlation of laboratory test data and binder performance on the road. Specification limits are suggested based on the testing of approximately 1 600 field samples. Limits cover resiliency, spray temperature, flow, softening point and site viscosity. Binder characteristics are also classified in order of importance for the optimum performance of roads with a crack reflection problem.

The paper will also discuss road sections laid in South Africa to evaluate solutions to the crack reflection problem. A jointed concrete pavement was successfully overlayed using bitumen-rubber. The basis for evaluating the old pavement was relative vertical movement at the joints.

Developments from the introduction of bitumen-rubber were the design and manufacture of the Crack-Activity-Meter (the CAM), and the use of the Sliding Plate Rheometer to identify effects of various mix variables and a rational design method for bitumen-rubber seals.

INTRODUCTION

Road pavements in Southern Africa consist mainly of locally available granular materials (1) with a relatively thin bituminous seal. The primary function of the seal is to provide a waterproof wearing surface to protect the water sensitive granular pavement layers. The resultant pavement is relatively inexpensive but also sensitive to poor maintenance which with the development of cracking will lead to the ingress of water resulting in potholing, shoving and rutting.

Water sensitivity of the sub-base or base layers has been affected by chemical stabilisation or by mechanical modification. The use of cementing agents such as Portland cement or road lime invariably leads to shrinkage cracking with the subsequent occurrence of reflection cracking. The ingress of water through these cracks results in pumping or structural failures.

The need to reduce or entirely prevent reflection cracking was the main reason for the introduction of bitumen-rubber to Southern Africa. The concept was radical in respect of the type of binder, its manufacture and the high application rate at which it was spray applied. Test methods as well as what characteristics of the binder were important had to be established. Also of prime importance was the correlation of laboratory test data and the actual performance of this binder on the road.

This paper discusses the performance of Arm-R-Shield bitumen-rubber of the now defunct Arizona Refining Company of Phoenix, Arizona over a period from November 1982 - August 1989 and also derived developments and benefits from its introduction.

OVERVIEW

Since its introduction in November 1982 to June 1989 in excess of 60 000 metric tonnes (2) of Arm-R-Shield bitumen-rubber have been used in Southern Africa. Applications have been in the form of stress absorbing membranes (SAM's), stress absorbing membrane interlayers (SAMI's), in hot premix (asphalt concrete) and as a crack sealant.

Figure 1 below shows the location of the full-scale road application sites in Southern Africa.
The climatic conditions vary from hot dry arid desert areas to warm, humid high rainfall regions as typified by Katima Mulilo in the Caprivi strip of Namibia/South West Africa to Durban on the east coast of Southern Africa.

The traffic conditions vary from under 1,000 equivalent light vehicles per day per lane up to 42,000 equivalent vehicles per day. The product was also used on various military air force bases.

Table 1 below shows the quantity of Arm-R-Shield bitumen-rubber manufactured over a six-year period which constitutes approximately 75% of the South African bitumen-rubber market for this period.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>CUMULATIVE</th>
<th>PER YEAR</th>
<th>TYPES OF APPLICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1982/83</td>
<td>15,000</td>
<td>2,500</td>
<td>Surface, Asphalt, Treatment</td>
</tr>
<tr>
<td>1983/84</td>
<td>42,000</td>
<td>7,000</td>
<td>(2%)</td>
</tr>
<tr>
<td>1984/85</td>
<td>72,880</td>
<td>12,000</td>
<td>(2%)</td>
</tr>
<tr>
<td>1985/86</td>
<td>105,392</td>
<td>15,000</td>
<td>(2%)</td>
</tr>
<tr>
<td>1986/87</td>
<td>146,064</td>
<td>20,000</td>
<td>(2%)</td>
</tr>
<tr>
<td>1987/88</td>
<td>187,416</td>
<td>30,000</td>
<td>(2%)</td>
</tr>
</tbody>
</table>

The basic composition of the bitumen-rubber consists of the following (by mass):

- 78% ± 2% 80/100 pen bitumen
- 2% ± 2% high aromatic extender oil
- 20% ± 2% ambiently ground scrap rubber

CORRELATION OF LABORATORY TEST DATA AND THE ACTUAL PERFORMANCE OF THE BITUMEN-RUBBER ON THE ROAD

Normal bitumen modified (2) by the addition of crumb rubber in the presence of extender oil transforms bitumen into a material that is simultaneously more resistant to load associated deformation at high temperatures (i.e. elevated softening point), and to cracking at low temperature (i.e. lower Fraas brittle point temperature).

Modification of bitumen into bitumen-rubber provides considerable improvement in the physical properties of the binder as well as binder-aggregate combinations. These include:

- increased adhesion and cohesion;
- improved modulus or stiffness;
- increased resistance to fatigue at high and low temperatures;
- resistance to reflection cracking;
- increased durability/weatherability

These improvements have resulted in a cost effective maintenance and rehabilitation strategy coupled with an improved road performance and an increased service life.

The road engineer knows that the complexity of pavement distress requires a choice of repair or rehabilitation options. The appropriate modification of bitumen binders has broadened the choices available to the engineer. Although conventional paving bitumens are adequate for many applications, the trend seems to be for bitumen to become the raw material for the next generation of pavement binders.

The use of modified binders in South Africa have been enhanced by the following, namely:

- reflection cracking from cement treated bases and sub-bases.
The materials design implementing bitumen-rubber interlayers and bitumen-rubber asphalt overlays, was aimed at inhibiting reflective cracking from a cement-treated base. This is the so-called "wet-process" where the rubber crumbs and bitumen are pre-blended at elevated temperatures to form the bitumen-rubber binder. A 80/100 penetration grade of bitumen was used. The limits agreed between the engineer and the contractor for the various test parameters, as well as the range of test results obtained during production are listed in Table III below.

**TABLE III: Properties of bitumen-rubber binder**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ring and Ball softening point (°C)</td>
<td>40 - 60</td>
<td>40 - 60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resilience (%)</td>
<td>10 - 20</td>
<td>10 - 20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plates flow (mm)</td>
<td>(to be tested)</td>
<td>(to be tested)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Site Quality Control**

Quality control on site consisted of:
- rubber crumbs, each new consignment was sampled and tested:
- 80/100 penetration grade bitumen, continuous routine testing as for all bitumens on site;
- bitumen-rubber binder, twice daily checks on plant. Samples drawn for tests of softening point, viscosity, ball resilience and plate flow;
- bitumen-rubber asphalt, one asphalt sample tested per 200 ton, but at least 2 per day.

**Mix Design**

Basically a modified open graded mix was used with an optimum binder content of 8% as determined by the Marshall method. Creep values had typical moduli between 100 and 250 MPa with an average value around 140 MPa. This is in excess of the minimum requirement of 80 MPa for E.4 (12 - 50 x 10^-6 E.80 per lane) traffic which is the highest traffic category in South Africa.

Indirect tensile testing (ITT) was also carried out. Values of between 500 and 1 000 kPa with an average of 800 kPa were measured.

Skid resistance, as measured with a break force trailer, showed that the skid resistance of the bitumen-rubber open graded asphalt to be superior to that of a standard gap-graded asphalt with rolled in chips. It was not however as good as for a shallow textured concrete pavement.

The serviceability survey shows that the open-graded bitumen asphalt performed better than a standard asphalt with rolled-in chips.

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2. National Route 3, Modderfontein/Buccleugh

This contract (4) was completed on behalf of the Department of Transport and is situated near Halfway House, between Johannesburg and Pretoria. Approximately 18 000 tonnes of bitumen-rubber asphalt and 100 000 sq. metres single seal as a stress absorbing membrane interlayer were constructed.
Road noise level. Noise levels recorded during comparative tests between the bitumen-rubber asphalt and adjacent shallow textured concrete pavement showed a 7 decibel lower noise level. Further noise reduction should be possible if the void content of the mixes were to be increased.

Bitumen-rubber semi-gap graded asphalt. The need for a bitumen-rubber asphalt with a low permeability was recognised. A semi-gap graded bitumen-rubber asphalt with 19 mm rolled in chips was developed on site and a section constructed. There appeared to be little correlation between the Marshall properties of mixes made up from bitumen-rubber and standard bitumen, given the same aggregate grading. Hence, on site they made use of the creep and ITT values for design purposes.

Both the bitumen-rubber asphalts and seals are performing well after four years in service after having been subjected to 42 000 equivalent light vehicles per lane per day.

3. Transvaal Road Department Road P.1/6 between Potgietersrus and Pietersburg – Ysterberg Section. (5)

Reconstructed in 1972/73 to what was then considered to be a medium-heavy pavement design (1-3 million E80 kN bearing capacity). The traffic at the time of construction was of the order of 2 000 vehicles per day with 19% heavy vehicles and has since risen to 3 700 vehicles per day with 14% heavies.

The pavement performed quite well functionally, but stabilisation cracks which developed exhibited signs of pumping fines shortly after construction and thus became "active". Relative vertical movements of between 0.04 and 0.14 mm were measured.

During 1982, the pavement was rapidly approaching the minimum trigger value, shown in Figure 4 below, and the pavement was provisionally put on the programme for heavy rehabilitation.

After being in service for more than five and a half years, no sign of pumping or deterioration has been observed. The road surface did, however, turn fatty in the slow-climbing lane in sections, yet never to the level of becoming bleedy or fatty.

![Figure 5](image1)
Condition of road October 1983

![Figure 6](image2)
Condition of road August 1989

The pavement has been effectively sealed preventing the ingress of water, the pumping distress and rapid pavement deterioration inhibited, if not completely stopped. The initial aim of at least "holding" the pavement for 2 years has not only been achieved, but extended to 5½ years.

It appears that the action taken might prove to be more than a mere holding operation in that it seems to be capable of extending this holding period up to 9 - 10 years. (3)

Figures 5 & 6 (above) are photographs taken of this road October 1983 and August 1989.

4. Transvaal Roads Department Road 343 Brits (Holmuherskop)

This road (6) had a long history of cracking as a result of the movement of the pavement due to the black clay sub-grade. Crack size 5 - 10 mm. (4)

Various maintenance strategies were tried over the years, including slurry sealing, single surface treatments, woven fabrics and patches etc.

![Figure 4](image3)
The structural performance graph of P.1/6 Ysterberg

Construction of the bitumen-rubber seal was carried out during Oct./Nov. 1983.
The bitumen-rubber single seal was constructed on 82/11/10 without any previous crack sealing or crack treatment.

As a direct result of the performance of the bitumen-rubber seal of this trial section, the complete road was re-sealed with bitumen-rubber in 1988. Usage of bitumen-rubber by the Transvaal Roads Department has also increased based on results of this experiment. Bitumen-rubber binder now amounts to approximately 25% of the binder used by the Transvaal Roads Department.

Monitor information regarding the binder and the pavement.

Binder laboratory test data from all contracts (2) have been stored in a data bank and have been analysed. (Figures 10 to 13) depict the general distribution of measured properties. Figure 10 shows resiliency as measured on oven-conditioning samples and Figure 11 on air-conditioning samples. The range and mean is the same in both cases, but the oven-conditioned samples show better uniformity. The 90 percentile value in both cases is 20.

Figure 7 shows the layout of the trial sections. Figures 8 & 9 show the condition of the road surface in November 1982 and in August 1989.

After six years this section of the road has been performing very well. Large 50 mm cracks have completely closed up and no surface cracking of the seal has taken place. This indicates that the moisture content of the sub-grade has been stabilised by the ability of the bitumen-rubber seal to seal the layer effectively and accommodate any movement in the pavement during the dryout/stabilising of the moisture content in the pavement layers.

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Figure 12
Frequency histogram of spray temperature

Figure 12 shows the temperature at which the binder was applied. A great variation exists with the mean lower than 190°C.

Figure 13
Frequency histogram of flow

The distribution of flow is shown in Figure 13, the average being 27 mm and 110% of the samples having a flow higher than 52.

Figure 14
Frequency histogram of site viscosity

The average viscosity, (Refer Fig. 14) just before application of the binder was 2700 cPs 10% lower than 1800 cPs.

Figure 15
Frequency histogram of softening point

Ring and ball softening point (Refer Fig. 15) varied from about 46°C to 76°C with an average of 61°C and 80% of the values between 55°C and 67°C.

If a 10% non-compliance with specification is acceptable, then the following can be used as an end performance specification:

- Resiliency: 20 min.
- Temperatures: 190°C - 205°C
- Flow: 52 max.
- Ring and Ball: 55 to 67°C
- Viscosity: 1800 cPs min.
Analysis of binder characteristics

As previously mentioned, performance can be defined in terms of several manifestations of distress, the most important one being reflection cracking. A detailed analysis of reflection cracking and the prevention thereof is presented in a different paper, but a statistical analysis of the results obtained for this study indicates that the more important parameters that influence performance are time or number of load applications, resiliency, ring and ball softening point, relative movement at a crack, rate of application of the binder and elastic recovery. Increases in time, ring and ball, resiliency, elastic recovery and rate of application reduces the extent of reflection cracking, whereas higher relative movements obviously increase the risk of reflection cracking. However, in combination, time or number of load applications, flow, ring and ball, relative movement and rate of application of binder relates most significantly with the extent of cracking. The interesting finding is that a higher flow is required in this particular combination of parameters. Table V shows the relative weights found for the different parameters (the findings in Table V are only presented as indicative of performance related properties and are based on the data accumulated so far in this study.)

The relative total contribution of the different parameters, as shown in Table V indicate that the ring and ball softening point temperature contributes to the highest degree in reducing reflection cracking, followed by relative vertical movement, the rate of application of the binder and lastly flow.

DURABILITY/WEATHERABILITY

Durability or age hardening due to environmental conditions normally causes bitumen to harden on the road with the passing of time. During visual inspections of roads in Phoenix, Arizona, and in South Africa, which had been in service for a period of 6-10 years, the impression was gained that the bitumen-rubber appeared not to age harden.

An attempt has been made to try and quantify this matter by recovering samples of bitumen-rubber from various roads. The samples of the binder were taken at the original time of spray application and binder characteristics determined in the laboratory.

The basis for comparison of sample testing has been softening point, flow and resiliency as these were the characteristics tested originally.

It was suspected that the physical properties of the recovered binder could be effected by the method of recovery of the binder from the aggregate. Correction factors were determined by taking bitumen-rubber with known laboratory tested values and making up single seals in trays in the laboratory. The binder was then recovered from these trays. The correction factor was then determined from the original and recovered values.

Table VI shows a comparison of the test values of the binder determined at the time of spraying compared with values determined from samples recovered from the road in 1989.

It can be seen from the values in Table VI that the physical characteristics have remained constant with time and would tend to indicate that very little or no age hardening of the bitumen-rubber has occurred with time. This seems to confirm visual observations of the binder on the road which appears to be alive, ductile, black in colour and still capable of preventing reflection cracking.

The photograph (Figure 16 below) shows the appearance of the bitumen-rubber at a typical inspection site taken in August 1989.

<table>
<thead>
<tr>
<th>SITE</th>
<th>SOFTENING POINT (°C)</th>
<th>FLOW</th>
<th>RESILIENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ORIGINAL</td>
<td>RECOVERED</td>
<td>ORIGINAL</td>
</tr>
<tr>
<td>1</td>
<td>60</td>
<td>59</td>
<td>77</td>
</tr>
<tr>
<td>2</td>
<td>55</td>
<td>56</td>
<td>52</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>67</td>
<td>38</td>
</tr>
</tbody>
</table>

Figure 16
Bitumen-rubber at inspection site August 1989
DEVELOPMENTS RESULTING FROM THE INTRODUCTION OF BITUMEN-RUBBER

The following developments have been a direct result of the introduction of bitumen-rubber to Southern Africa. It is the firm belief of the author that these findings will contribute greatly to the understanding of the cracking mechanism in pavements and to the most cost effective method of dealing with this problem.

The use of bitumen-rubber to inhibit reflection cracking, highlighted the need to investigate the phenomenon of load associated crack movement and crack reflection. It also highlighted the need to evaluate the field performance of bitumen-rubber and subsequently other modified binders.

The development of the Crack-Activity-Meter (CAM) and its use with the South African Heavy Vehicle Simulator (HVS) has led to an improved understanding of crack movement.

The Crack Activity Meter (CAM)

The Crack-Activity Meter (CAM) (3), shown in Figure 17, can measure both relative vertical and horizontal crack movement simultaneously. Data is recorded continuously as a 40 kN wheel load approaches the point of measurement and passes over it. A plot of crack movement versus the distance of the wheel from the measuring point is therefore the influence line of crack movement (3).

The CAM can be used to measure crack movements on a pavement at different stages during its structural life. Typical influence lines of crack movement recorded on a cemented base pavement are shown in Figure 18. A mobile data acquisition system for the CAM has also been developed and can be used to measure crack movement on any road.

Crack movement behaviour

Naturally, the crack movements can change if the factors influencing them change. Changes in crack movement are brought about artificially during HVS testing when accelerated trafficking causes changes in parameters such as the shape of the deflection basin or the size of the blocks defined by the cracks. The peak crack movements recorded at various stages of an HVS test can be plotted against trafficking to produce a crack movement behaviour curve (Figure 19). The CAM can thus be used in conjunction with the HVS to determine how the crack movement will change as a pavement deteriorates.

Laboratory Fatigue Testing

The Crack Movement Simulator (CMS) (4) was developed to investigate the fatigue characteristics of thin layers of conventional and modified binders under simulated crack movement and controlled conditions in the laboratory. This apparatus consists of a frame onto which the sample is fixed, a cabinet for controlling the testing temperature and an LVDT which measures the actual movement applied to the sample. The apparatus is used in conjunc-

Figure 17
The crack-activity meter

Figure 18
Typical influence lines of crack movement obtained on the MR27

Figure 19
Crack movement behaviour curves obtained during HVS testing
tion with the INSTRON testing facility which controls the movement and applies the load. The CMS can be used in two configurations to simulate horizontal and vertical crack movement respectively. The samples are prepared by heating the binder to a specified temperature and then spreading it evenly over two plates set up in a rig such as shown in Figure 20. The two plates are separated by a metal sheet of known thickness to control the simulated crack width. Two bars are fixed onto the two plates to prevent damage to the sample prior to the test. These bars and the metal sheet are removed when the sample is fixed in the CMS.

Figure 21 shows the configuration of the CMS for horizontal crack movement. The plates on which the samples are cast are fixed with epoxy onto two similar, vertically positioned plates. The top plate is kept stationary while the bottom plate is moved repetitively by the ram of the INSTRON facility.

The factors influencing the fatigue life of the sample that were varied in this work were:

* the testing temperature (usually 5°C and 12.5°C but lower temperatures were also used in some cases);

![Figure 20](image1)
**Figure 20** Bitumen-rubber sample prepared in rig

![Figure 21](image2)
**Figure 21** The crack movement simulator

![Fatigue Curves](image3)

Figure 22 shows the fatigue curves of all materials tested to date. It can be noted that, for the materials tested, the modification of bitumen will lead to an improvement in the fatigue behaviour of the material. However, it should be noted that these results must still be correlated with the field performance of the materials in the N3 trials before final conclusions can be made. The above results will also be correlated to the standard test results conducted on the same materials. Furthermore, it must be kept in mind that the selection of a surface treatment should be done on the basis of the activity of the cracks. Therefore, materials with a lesser ability to stop crack reflection could be the optimum choice (also taking their cost into account) for specific problems where extreme crack movements are not present.

**Interim design procedure**

The CAM system is currently available as a service provided by RTT to the Road Authorities. It has been used by the Department of Transport on a number of occasions to aid rehabilitation design decisions on pavements where crack reflection was considered to be a possible problem. As an example, the work done on the N4/3 near Witbank, which is a pavement with a cement-treated base, will be discussed here.

An initial assessment (according to TRH 12) was first conducted for this pavement to determine the condition of the pavement and to divide the pavement into uniform sections, representing good, average and poor conditions. The CAM was then used on 6 to 10 selected sites to determine the range of crack movement on the pavement. The block size and a deflection basin measurement were also recorded at each measuring point.
The correlation of crack movement with the peak deflection is shown in Figure 23. The crack movement classes discussed above are also shown in this figure. For design purposes the 95th percentile line shown in Figure 23 was used to determine the peak deflection values between which the crack movements is in the low, medium or high range. The crack movement on this pavement fell mainly in the middle range (100 mm to 200 mm). On two of the sites where crack movements were measured, high values were recorded (greater than 200 mm). This was due to the fact that the road had been built over a "vlei-like" area. The data recorded indicated that crack movements above 100 mm could be expected if the surface deflection was above 0,3 mm. Crack movements between 100 mm and 200 mm could be expected if the surface deflection was between 0,3 mm and 0,5 mm.

Based on the above and the interim classification of crack movement appropriate remedial actions could be selected for each uniform section on this pavement.

![Figure 23](image)

**Figure 23** Correlation of crack movement with peak deflection

**RATIONAL DESIGN FOR BITUMEN-RUBBER SEALS**

Semmelink et al (8) has proposed a national design of bitumen-rubber seals according to the NITRR method using a modified tray test. The bitumen-rubber seal

The bitumen-rubber seal is basically also a single seal. However, there is a very important difference, namely the type of binder being used. In the case of the bitumen-rubber seal the stone tends to be differently orientated from that in a normal single seal due to the greater adhesive property of the bitumen-rubber binder.

When stone is dropped by the chip spreader it tends to drop in a random manner. This means that the longest dimension of the chips often tends to be vertical when the chips make contact with the binder. In the case of normal binders, the initial adhesive bond is weak enough for these chips to be rolled flat. However, in the case of bitumen-rubber seals the initial contact is firm and even rolling does not seem to be able to flatten the stone layer. For this reason the design method simulates this condition.

![Figure 24](image)

**Figure 24** Schematic illustration of the modified tray test

**The modified tray test**

The modified tray test is used to determine the effective layer thickness (ELT) and void content in single or double layers of aggregate to be used in surfacing seals. The test equipment consists of a circular tray with an area of 0,05 sq. metre and a wall height of 50 mm. A shoulder piece, fitted snugly on top of the tray and with the same internal diameter as the tray, is attached to a loose-fitting cloth membrane. The purpose of the membrane is to prevent the "density sand" from flowing into the voids between the aggregate (see Figure 24).

**SOME METHODS OF EVALUATING BITUMEN-RUBBER ASPHALT AND BINDERS**

Four test methods, Hugo & Nachenius et al (9) were employed to study the properties of the bitumen-rubber binder and bitumen-rubber asphalt concrete. The tests were used in conjunction with a rehabilitation project on the N2 concrete freeway between Cape Town and Somerset West. The project was completed in November 1986 and included a SAMI and a 40 mm bitumen-rubber overlay. The type of mix used in the bulk of this contract involved pre-blending of the bitumen-rubber binder in the mixing plant. This is also sometimes referred to as the "Wet Method" type of bitumen-rubber asphalt. It should be noted that this was the Sahauro type technology in which no extender oil was used in the binder.

A short section of the overlay was constructed using the "Dry Method" type asphalt. In this process the rubber crumbs are added to the hot aggregate before introducing the bitumen-rubber.

The four test methods used were:
1. Sliding plate rheometer tests for binders;
2. Repeated load indirect tensile tests for asphalt concrete;
3. Indirect tensile strength for asphalt concrete; and
4. Indirect tensile strain for asphalt concrete.

The results showed the Wet Method to have a lower moduli, whilst showing a reduced tendency to deform in a vertical direction when subjected to indirect tensile stresses.

The study conclusion was that despite stripping of the binder from the aggregate the overlay is still performing well. No incidences of crack reflection have yet been noticed. Bitumen-rubber asphalt should therefore be seriously considered as a cost-effective alternative for the rehabilitation of cracked asphalt or concrete pavements.
Improvements in testing procedures will allow users to use this material with increasing confidence.

REFERENCES


