A REVIEW OF THE ROAD PERFORMANCE OF A MODIFIED BINDER IN SOUTHERN AFRICA OVER A SIX-YEAR PERIOD

R H RENSHAW* OR P J STRAUSS** E G KLEYN***

ABSTRACT

Arm-R-Shield bitumen-rubber was first introduced to South Africa in late 1982. This concept was radical in respect of the type of product, its manufacture and the very high application rates at which it was spray applied. Technical as well as application data from the USA was based on empirical information. Test methods as well as what characteristics of the binder were important had to be established. Of prime importance was the correlation of laboratory test data and the actual performance of the binder on the road. This paper reviews various full-scale usage of the modified binder in various climatic areas of the RSA and their performance over date. Specification limits are suggested in respect of resiliency, spray temperatures, flow, softening point and viscosity. Binder characteristics are also classified in order of importance for the optimum performance of roads with a reflection crack problem.

INTRODUCTION

What is a modified binder?

Bitumen is a thermoplastic material used in a variety of ways, such as paving binders, roofing adhesives and sealants. However, as a road construction material, it is hard and brittle in cold weather, and soft and fluid in hot weather. Modification of bitumen can take the form of additives or by chemically changing the rheological properties of the bitumen. All forms of additives and modifiers tend to be lumped together without due consideration regarding their application or intended use.

The Strategic Research Programme (SHARP) (1) of the United States National Research Council has identified the following suggested classification of Asphalt Modifiers as shown in Table I below:

<p>| TABLE I |</p>
<table>
<thead>
<tr>
<th>Suggested classification of asphalt modifiers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mineral Filler (dust, lime, Portland cement, carbon black, sulphur)</td>
</tr>
<tr>
<td>2. Extender (sulphur, lignin)</td>
</tr>
<tr>
<td>3. Rubbers</td>
</tr>
<tr>
<td>a. Natural Latex</td>
</tr>
<tr>
<td>b. Synthetic Latex (styrene-butadiene or SBR)</td>
</tr>
<tr>
<td>c. Block Copolymer (styrene-butadiene-styrene or SBS)</td>
</tr>
<tr>
<td>d. Recycled Rubber</td>
</tr>
<tr>
<td>4. Plastics (polyethylene, polypropylene, ethylene-vinyl-acetate or EVA, polyvinyl chloride or PVC)</td>
</tr>
<tr>
<td>5. Fibres (asbestos, rock wool, polypropylene, polyester)</td>
</tr>
<tr>
<td>6. Metal Compounds (manganese and other mineral salts)</td>
</tr>
<tr>
<td>7. Coal Tar Modifiers</td>
</tr>
</tbody>
</table>

This paper will discuss the road performance of bitumen-rubber (manufactured from scrap reclaimed rubber) in surface treatments and in hot premix over a six-year period from November 1982 to January 1989. The specific product is Arm-R-Shield and the technology is that of Phoenix, Arizona, USA.

The bitumen-rubber technology was developed in the early sixties by Charlie McDonald of Phoenix, Arizona. Bitumen-rubber was introduced in 1982 in order to make a binder available to the road construction industry that would be successful in substantially reducing or completely eliminating reflection cracking caused by cement-treated bases.

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*** Chief Materials Engineer, Transvaal Roads Department

The quantities manufactured in South Africa for a 5-year period are given in Table II below:

<p>| TABLE II |</p>
<table>
<thead>
<tr>
<th>Usage of bitumen-rubber 1983-1988 in Southern Africa</th>
</tr>
</thead>
<tbody>
<tr>
<td>YEAR</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>1983/84</td>
</tr>
<tr>
<td>1984/85</td>
</tr>
<tr>
<td>1985/86</td>
</tr>
<tr>
<td>1986/87</td>
</tr>
<tr>
<td>1987/88</td>
</tr>
<tr>
<td>1988/89</td>
</tr>
</tbody>
</table>

This paper also reports on the actual performance of bitumen-rubber on the road correlated with laboratory determined binder characteristics and will discuss additional benefits derived from the use of bitumen-rubber namely:

- Cost effectiveness
- Long-term durability/weatherability
- The use of surface treatments on high volume/high load roads where surface treatments were previously considered impractical
- As a holding action during periods of non-availability of funds for rehabilitation and reconstruction of the road network.

1 THE DEMANDS MADE ON A BINDER

1.1 The function of road surfacing.

Road surfacing should provide the following, namely:

- Comfortable and safe riding surface under all weather conditions
- Wearing surface
- Waterproof surface
- Skid resistant surface
- Cost effective road surface
- Relative maintenance free surface
- Stable road surface in respect of:
  - Deformation (rutting, corrugations)
  - Cracking (all forms of cracking)
  - Disintegration of surface (asphalting, potholes, edge breaks)
  - Smoothing of surface texture (bleeding, polishing)
1.2 The use of modified binders?

After the Interstate Highway construction era in the USA it became evident that maintenance of the entire US highway system had grown to a great challenge. After decades of modest technological growth, the paving industry is now changing rapidly in North America. The European paving industry (1) has also changed from conventional maintenance procedures to new techniques using modified bitumens. The cost of bitumen has risen dramatically along with oil and petrol. This high cost made it more realistic to consider modification of bitumen and the difference in cost for this upgraded material was more acceptable. In addition the pavement industry was more amenable to change, because all participants were involved and prepared for innovation.

A specific experience (2) relates to the performance of bitumen-rubber which was introduced to the city of Phoenix’s pavement maintenance programme in the late 1960’s. The conclusions reached were as follows:

- The average life expectancy of bitumen-rubber will be 10-12 years with no maintenance.
- A conventional bitumen seal life expectancy is 6-8 years with some maintenance such as crack filling and pothole repair requirement in year 3.
- Although bitumen-rubber is initially more expensive than the conventional surface treatment, in the long term this material has turned out to be more economical: this is due to reduced maintenance and an increased life.

Normal bitumen modified 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. Premature cracking of preformed wearing courses particularly with gap-graded and semi-gap graded mix types are also a major problem.
- Non-availability of funds has necessitated the use of “holding actions”. Single surface treatments with bitumen-rubber on E3 and E4 category national roads as well as provincial roads have proved to be very successful.

2 THE ROAD PERFORMANCE OF MODIFIED BINDERS

The main reasons for the introduction of bitumen-rubber to South Africa in 1982 was to make a binder available to the road construction industry that would be successful in substantially reducing or completely eliminating reflection cracking caused by cement-treated bases.

In order to evaluate the performance of bitumen-rubber in South Africa several sections were constructed.

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

- 78% + 3% 80/100 pen grade bitumen
- 2% + 2% High aromatic extender oil
- (not a diluent)
- 20% + 2% Ambiently ground crumb rubber

ex Paragon Rubber

2.1 Sites and their location

The sites and their location which are evaluated are shown in Table III below:

<table>
<thead>
<tr>
<th>ROAD</th>
<th>AUTHORITY</th>
<th>LOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1-1</td>
<td>Transvaal Roads Dept.</td>
<td>Potgietersrus-Pietersonburg</td>
</tr>
<tr>
<td>Road 347</td>
<td>Transvaal Roads Dept.</td>
<td>Bela Bela</td>
</tr>
<tr>
<td>NR 27</td>
<td>Cape Roads Dept.</td>
<td>Stellenbosch</td>
</tr>
<tr>
<td>M3</td>
<td>National Transport</td>
<td>Somerset West</td>
</tr>
<tr>
<td>M2</td>
<td>National Transport</td>
<td>Randloe-New Goudenberg</td>
</tr>
</tbody>
</table>

2.2 Background Information of study sites

2.2.1 Transvaal Road Department Road P1/6 between Potgietersrus and Pietersonburg - Ysterburg Section

Reconstructed in 1972/73 to what was then considered to be a medium-heavy pavement design (1-3 million 1800 KN bearing capacity). The traffic at the time of construction was of the order of 2 000 vehicles per day with 13% heavy vehicles and since released to 7 700 vehicles per day with 14% heavies.

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

During 1982, the pavement was rapidly approaching the minimum trigger value, shown in Figure 1 below, and the pavement was provisionally put on the programme for heavy rehabilitation.

![Figure 1](image-url)

The structural performance graph of P1/6 at Ysterburg
Construction of the bitumen-rubber seal was carried out during Oct./Nov. 1983.

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 bloody or fatty.

Figures 2 & 3 (above) are photographs taken of this road in October 1983 and January 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 5+ 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)

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

The bitumen-rubber single seal was constructed on 82/11/10 without any previous crack sealing or crack treatment.

Figure 4 shows the layout of the trial sections. Figures 5 & 6 show the condition of the road surface in November 1982 and in January 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.
As a direct result of the performance of the bitumen-rubber seal of this trial section, the complete road has been 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.

2.2.3 Cape Roads Department MR 27 Stellenbosch

This road was constructed in 1967 with a cement treated base course. Reflection cracking occurred through the premix wearing course and subsequently the pavement was sealed in 1979 with a single seal using 13,2 mm aggregate. One year after the construction of the single seal the cracks reflected through and severe pumping resulted.

Bitumen-rubber single seal trial sections were constructed on 6/12/82. Unprecoated 6,7 mm aggregate was used and two spray application rates, having 3,30 lit./sq. metre in the slow lane and 2,90 lit./sq. metre in the fast lane.

The slow lane fatted up considerably within 4 - 6 weeks of construction of the seal due to the heavy traffic conditions. However, no bleeding or resultant pick occurred on the section where 3,3 lit./sq. metre were applied.

Figure 7 shows the lay-out of the trial section and Figure 8 shows the condition of the road before sealing in December 1982.

Figure 9 shows the condition of the road in March 1988.

After 5 years service approximately 9,5% of the cracks reflected through and the road became very fatty with no pick up. This fattening up was due entirely to embankment and the low application rate of 6,7 mm stone.

Figure 7 M.27 trial layout

<table>
<thead>
<tr>
<th>NOT TO SCALE</th>
<th>DATE LAID : 06/12/82</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPICAL LAYER SECTION OF PAVEMENT</td>
<td></td>
</tr>
<tr>
<td>CONCRETE</td>
<td>MEDIAN MAIN ROAD 27</td>
</tr>
<tr>
<td></td>
<td>( STELLENSBOGHS MUNICIPAL AREA )</td>
</tr>
<tr>
<td></td>
<td>SHOULDER</td>
</tr>
<tr>
<td></td>
<td>Section 1</td>
</tr>
<tr>
<td></td>
<td>Section 2</td>
</tr>
<tr>
<td></td>
<td>Section 3</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
</tr>
</tbody>
</table>

Figure 8
Condition of MR.27 December 1982

Figure 9
Condition of MR.27 in March 1988

2.2.4 N2/Somerset West

The pavement of this section of road consisted of a jointed concrete with flexible shoulders. Due to a secondary chemical reaction between aggregate and portland cement, cracking occurred, which rapidly developed into structural cracking under traffic. The mechanism of failure therefore was cracking which allowed water into the sub-grade. Paving of the sub-grade in turn led to punch-outs and rehabilitation in the form of overlays were considered necessary.

Certain experimental overlays (5) were built in 1982, one of which was a bitumen-rubber asphalt, the first under contract in Southern Africa. A semi-open graded mix was used with 7,8% bitumen-rubber binder and 8,9% laboratory voids were obtained with a stability flow ratio of 1,3. The thickness of the asphalt was 35 mm average and the relative vertical movements at the joints before overlaying ranged from 0,01 mm to 0,41 mm.

After 6 years of service, cracks are now coming through especially where relative movements were higher than 0,25 mm.

2.2.5 N2-26 & 274, Umzimkulu to N1

A bitumen-rubber single seal was applied on the N2-26 between Umbang, Umzimkulu and the Umzimkulu intersection and on the N2-27 from Bethelsdorp to N1 during January to March 1985. The seal consisted of an application of emulsion at 0,5 litres/sq. metre followed by 2,4 litres/sq. metre bitumen-rubber and precoated 13 mm stone at 0,611 cubic. metre/sq. metre. Spray
During November 1985, some bleeding started to occur, mainly north of km. 20 on the N2-27. An in-depth investigation by coring as well as visual observation led to the conclusion that embedment was the primary cause of the problem. Figure 10 shows a view of the road where the problem was particularly bad. In this particular case, the shoulder was very lightly treated with pre-coated chippings at the time of the construction of the original asphalt. Embedment of the seal subsequently occurred. Figure 11 clearly shows the embedment. Other sections where no bleeding occurred showed no embedment. (See Figures 12 and 13).

The relative vertical movements on this particular contract varied from 0.01 mm to 0.35 mm. On about half the section of road, cracks were widened, using the "hot dog" equipment, and sealed. On the other half the seal was placed directly on top of the existing asphalt. In the first case, (sealed cracks) very few cracks have reflected through and in the other half cracks have already reflected, particularly where the original crack movements are higher than 0.2 mm.

![Figure 10](image1.png)

**Figure 10**
Condition of road surface with embedment

![Figure 11](image2.png)

**Figure 11**
Core showing embedment on old shoulder

![Figure 12](image3.png)

**Figure 12**
Surface with no embedment

![Figure 13](image4.png)

**Figure 13**
Core showing no embedment

3. DATA BANK OF BINDER CHARACTERISTICS AND SITE DATA

3.1 Monitor information regarding the binder and the pavement

Binders from all contracts have been stored in a data bank and have been analysed. Figures 14 to 19 depict the general distribution of measured properties. Figure 14 shows resiliency as measured on oven-conditioning samples and Figure 15 on air-conditioned 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 15  
Frequency histogram of air resiliency

Figure 16  
Frequency histogram of spray temperature

Figure 16 shows the temperature at which the binder was applied. A great variation exists with the mean lower than 190°C.

Figure 17  
Frequency histogram of flow

The distribution of flow is shown in Fig. 17, the average being 27 mm and 110% of the samples having a flow higher than 52.

Figure 18  
Frequency histogram of site viscosity

The average viscosity, (Refer Fig. 18) just before application of the binder was 2,700 cPs with 10% lower than 1,800 cPs.

Figure 19  
Frequency histogram of softening point

Ring and ball softening point (refer Fig. 19) 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 1,800 cPs min.

3.2 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.
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.)

### Table V

Parameters influencing reflection cracking

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Relative Total Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ring &amp; Ball (°C)</td>
<td>-0.17</td>
</tr>
<tr>
<td>Relative movement (mm)</td>
<td>-0.11</td>
</tr>
<tr>
<td>Rate of application</td>
<td>-0.13</td>
</tr>
<tr>
<td>(liters/square metre)</td>
<td>0.01</td>
</tr>
<tr>
<td>Flow (mm)</td>
<td>0.01</td>
</tr>
</tbody>
</table>

The relative total contribution of the different parameters, as shown in Table V indicates 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.

### 4 Binder Characteristics Recovered from Various Sites

Ageing of binders has always been of concern. Since modified binders were considered a new product in 1982 an attempt was made to recover binder at specific areas where the original characteristics were known. Limited test data from recovered samples seems to indicate very little change (max. of 5% change in six years) in binder properties. It must be remembered that the recovered sample represents the full thickness of binder on the road. Ageing of the outer skin of binder could not necessarily be determined separately in this way.

Visual observations of the binder on the road in January 1989 showed the following:
- the material still appears to be very active, black and sticky. This suggests that very little or no oxidation has occurred;
- the binder is still very difficult to remove from the road and to remove individual stones from the matrix. This suggests that the adhesion is still very good;
- the binder is still capable of being extended by pulling for some distance without cracking. This shows that the cohesion is still good;
- the softening point of the binder appeared to be higher than the temperature of the road surface as the binder was not fluid. The photograph (Figure 20 below) shows the appearance of the bitumen-rubber at a typical inspection site.

![Figure 20: Bitumen-rubber at inspection site, January 1989](image)

### 5 Conclusions and Discussions

When Arm-R-Shield bitumen-rubber was first introduced into South Africa in October/November 1982 much skepticism was expressed by the Road Industry regarding the ability of this new product to:

- reduce and in most cases completely eliminate reflection cracking due to cement stabilised sub-grade layers; on average it was found that approximately 85% of the cracks have not reflected after 5 years;
- to be spray applied at high application rates of 2,2 - 3,0 litres/sq. metre;
- not be prone to bleeding when applied at high application rates although fattening up does occur;
- have outstanding durability until now (7 years); and
- be cost effective in view of its high initial cost when expected life is compared to that of normal pen grade bitumens.

Performance of bitumen-rubber on the problem roads reported on in this paper has been very good and has amply demonstrated its ability to perform as originally claimed.

### Acknowledgements

The authors wish to extend their appreciation to the Chief Director of the Department of Transport, the Executive Director of the Roads of the Transvaal and Cape Provincial Administration for their permission to publish relevant data in this paper.

### References


<table>
<thead>
<tr>
<th>Reference</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Private communication with Messrs BKS &amp; Matrolab.</td>
</tr>
</tbody>
</table>