Polymer-Modified Bitumen Emulsion as Chipseal Binder in High Stress Areas on New Zealand Roads

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Executive Summary

Although polymer-modified bitumen (PMB) has been used in New Zealand as a chipseal binder since 1980, the expected advantages of this high strength binder in areas subjected to high traffic stress have not occurred. The main difficulty with hot applied polymer-modified binders appeared to be the poor chip wetting characteristics. This is related to the decreased flow properties of the PMB and leads to extensive early chip loss.

A company in Australia, Sami Pty Ltd, developed a high binder content (78%) polymer-modified bitumen emulsion (trade name Samiflex E) that has the potential to overcome the chip wetting problems. The research recorded in this report was initiated in 1993 and ran to 1995 to assess the ability of this new product to withstand high traffic stresses on New Zealand roads.

For high stress areas, Sami Pty Ltd recommends that the emulsion be used in a "racked in" sealing system (i.e. in which binder is applied, followed by the application of larger chip, then smaller chip). This sealing system was trialed in four areas, Auckland, New Plymouth, Wellington and Porters Pass, comprising eight sites, and monitored for one year (1995). Two control sections, using a two-coat seal with 180/200 grade bitumen, were trialed as well.

Advantages of the system that are evident from this trial are:

- The ability to apply high emulsion application rates without run-off.
- The ability to construct the system over a very variable surface texture.
- The reduced risk of polymer degradation related to the low storage and application temperatures.
- The excellent adhesion obtained between the sealing chip and the binder.

At this stage the only improvement that could be made is in the rate of break of the emulsion which, for these trials, was up to 5 hours. However, this can partly be explained because the product used for the trials had to be transported from Australia, and needed to be more stable.

After one year of service (1995) the trial sections had performed well. Early chip loss on small areas on the roundabouts and one other site which expanded in area over a year could possibly have been contained if repairs had been undertaken within the first two weeks of construction.

In general, these trials have successfully demonstrated that the system is applicable to New Zealand roads, although the control sections have also performed well.

They have shown too that in very high stressed areas, such as roundabouts, a sealing system may need to be completed in two phases. For example some areas of chip loss occur after the initial construction but, if they could be repaired within a short time, further early life chip loss is unlikely to continue.

The Samiflex E sealing system is considered to be a lower failure risk treatment than seals constructed with hot applied polymer-modified binder, and thus is a viable alternative surfacing treatment for use on New Zealand roads.

Abstract

A high binder content (78%) polymer-modified bitumen emulsion used in a "racked-in" sealing system was trialed from 1993 to 1995 as a surfacing in high traffic stress areas for New Zealand roads. The perceived advantage of this sealing system was that the polymer-modified emulsion would have better initial chip adhesion than a hot applied polymer-modified bitumen.

Four trial areas, comprising eight sites, were constructed using this system, including two roundabouts, and monitored for one year (1995). On two of the sites, control sections were constructed using a two-coat seal with 180/200 grade bitumen.

Although the control sections also performed well, the polymer-modified emulsion sealing system is concluded to be a viable surfacing treatment for high traffic stress areas on roads.

1. Background

Polymer-modified binder (PMB) chipseals have generally been regarded in the road industry in New Zealand as having a number of potential advantages over unmodified seals, especially in high traffic stress problem areas. However, PMBs are significantly more difficult to use for the following reasons:

- The polymers used are susceptible to thermal degradation. This is exacerbated by the need to mix and spray the PMBs at temperatures in excess of 180°C if the binder contains more than 4% polymer. This is because the viscosity increases compared to unmodified binders at elevated temperatures.

- The poor chip wetting characteristics. This is related to the decreased flow properties of the modified binder.

To construct a successful PMB chipseal, the conditions and practices need to be ideal, such as:

- an assurance of a period of hot weather after the construction;
- a shade air temperature during construction of 25°C or greater;
- conditioned chip, e.g. very clean, dry or lightly pre-coated;
- two-coat seals, not single coat seals;
- minimised mixing and storage times;
- carefully controlled construction methods;
- increased rolling requirement.

Because of the constraints imposed by the rigorous conditions required to maximise the potential success of a PMB chipseal, sealing contractors tend not to favour PMBs. In the past a number of PMB seals have been constructed under non-ideal conditions, leading to failure and lack of confidence in the product.

Polymer-modified binder chipseals have been advocated for use in order to:

- retard crack reflection;
- retard flushing;
- reduce bleeding;
- hold chips on high stressed areas.

In New Zealand the problem of chip retention on bends, intersections and roundabouts has been seen as an area where polymer modification could have very significant benefits. The increased strength of PMBs would appear to be ideally suited to this application.

Field experience, however, tends to suggest that the poor chip wetting characteristics of PMBs, especially at higher degrees of modification, makes the use of these binders a relatively high risk option. Even when two-coat seals have been used, with a highly modified PMB in the first coat followed by a non-modified second coat in order to lock the seal in position, performance expectations have often not been met.

Emulsifying the PMB has long been postulated as overcoming construction difficulties, because of the excellent wetting characteristics of emulsions, even in damp and cool conditions, and the lower temperatures (<100°C) required for storage and spraying. However, there have been technical problems with manufacturing emulsions containing significant quantities of polymers (e.g. >2%) due to the dramatic increase in viscosity of the PMB to be emulsified.

A company in Australia, Sami Pty Ltd, developed an emulsion (trade name Samiflex E) which contains significant amounts of polymer modification. The advantages over a standard unmodified emulsion are claimed to be:

- Significantly enhanced properties of the residue binder after curing, leading to:
  - retardation of crack reflection;
  - flushing retardation;
  - reduced bleeding;
  - improved ability to hold chips on high stressed areas;
  - ability to hold chips on low stressed areas with a reduced binder application rate.

- Contains a significantly higher binder content, reducing the amount of water required to transport the product.

- Advanced thixotropic properties, allowing much higher than normal emulsion application rates to be applied, without run-off problems.

A joint Transit New Zealand–industry research project was carried out between 1993 and 1995 in order to assess the ability of this new product to withstand high traffic stresses. If research found that the claims were true, Samiflex E may provide an excellent remedial treatment for problem pavement surfacings, and increased life for standard surfacing.

2. Sealing System

For these New Zealand trials of the PMBs, the sealing system as proposed by the suppliers was assessed for its ability to withstand high traffic stresses in problem areas on New Zealand roads.

The system consists of a polymer-modified bitumen emulsion with a total binder content of 78%. The construction system uses a "racked in" method, which consists of the application of the binder followed by the application of the larger then the smaller chip. With this system it is important to ensure that there are sufficient "windows" in the first chip application so that the second chip is in contact with the binder. Typically the application rate of the first chip is approximately 70% of that applied for a single coat seal. The sealing chip is pre-coated with a proprietary product in accordance with the manufacturer's instructions.

The determination of the binder and chip application rates was under the control of the system suppliers. For these trials, supervision was provided by Sami Pty Ltd, Australia.

For all the trials, the same basic emulsion used had been manufactured in Australia. The residual binder was designed to comply with the AUSTROADS (1997) framework specification for an SBS polymer-modified binder.

3. Trial Areas

Four formal trial areas were selected to cover a range of traffic and environmental conditions. The first trial, in New Plymouth, was basically a construction trial designed to investigate the practical difficulties that could arise, and to confirm that the design of the system as practised in Australia was applicable to New Zealand conditions. The other formal trials were constructed in Auckland, Wellington, and at Porters Pass where two control sections were incorporated using a two-coat seal with straight bitumen.

Details of the sites are given in Table 3.1. Except for the New Plymouth site, all were considered by the road controlling authority to be areas where normal chipsealing techniques, including two-coat seals, would not have been considered as a surfacing option.

The New Plymouth and Porters Pass sites were existing chipseals with signs of flushing. The existing surfaces at the Auckland and Wellington sites were a combination of asphaltic concrete, chipseals in good order, and areas with significant chip loss, often on the same site. The variation in surface texture was such that normally pre-seal repairs would have been performed to even out the surface texture. For these trials no maintenance to the existing surface was performed.

Table 3.1 Trial site details.

Location	Site	Traffic (v/d)	Date constructed	Chip sizes	Comments
New Plymouth	SH3, Waiwhakaiho Hill	16,700	7/12/93	3/5	State highway open road.
	SH3, Crematorium Hill	6,400	7/12/93	4/6	State highway open road.
Auckland	Coronation Road	4,100	8/2/94	3/5	Residential with one bend subject to buses.
	Hastie Avenue	600	8/2/94	3/5	Industrial and residential traffic with industrial crossing.
	Lambie/Cavendish Roundabout	4,500	9/2/94	3/5	33 m diameter servicing commercial and light industrial area.
Wellington	Newlands Roundabout	7,500	31/1/94	3/5	7 m diameter on route to landfill area.
	Crawford Road	8,000	1/2/94	3/5	Winding grade on trolley bus route, gradient 10%.
Christchurch	SH73, Porters Pass	940	20/1/94	3/5	Area subjected to snow grading in winter, including gradient of 9.8%.

4. Laboratory Tests

The viscosity of the emulsion was determined using a Brookfield viscometer model HAT and the No. 1 spindle at 70°C, as specified in TNZ M/1:1989 *Specification for Asphaltic Bitumen*. Two samples were tested, the first from the New Plymouth trial and the second from the Wellington trial.

Test results are given in Table 4.1, together with results from a typical 68% binder content emulsion and the binder content in accordance with BS 434, Part 1, Appendix F:1984.

Table 4.1 Brookfield viscosity at 70°C of PMBs at two trial sites and of a typical CQ70 emulsion.

Spindle speed (rpm)	Viscosity 70°C (milliPas)		
	New Plymouth	Wellington	CQ70 typical
0.5	13,200	15,200	2,240
1.0	7,700	9,000	1,800
2.5	4,040	4,800	1,272
5.0	2,560	3,200	964
10.0	1,670		
Binder content	78.0	81.0	68.0

CQ70 - typical emulsion

In addition, the Wellington sample was subjected to cycles of increasing and decreasing shear over the range of spindle No. 1 speeds of 0.5 to 10 rpm, in order to determine if any time-dependent changes occurred in the emulsion. These results are given in Table 4.2.

Table 4.2 Effect of shearing time on viscosity at 70°C, of the Wellington sample.

Spindle speed (rpm)	Viscosity 70°C (milliPas)					
	Increasing	Decreasing	Increasing	Decreasing	Increasing	Decreasing
0.5	15,200	13,400	13,400	14,000	14,000	12,400
1.0	9,000	8,200	8,200	8,200	8,400	8,000
2.5	4,800	4,720	4,720	4,480	4,480	4,640
5.0	3,200	3,040	3,000	2,980	2,980	2,720

There is a slight decrease in viscosity with shearing, but the difference is not regarded as substantial.

As the emulsion viscosity is relatively high, it was tested with a Brookfield No. 2 spindle in order to allow a wider range of spindle speeds. These results from the Wellington sample, together with results from a CQ70 emulsion, are given in Table 4.3.

Table 4.3 Brookfield viscosity at 70 °C, spindle No. 2 of the Wellington sample and of a CQ7 emulsion.

Spindle speed (rpm)	Viscosity 70 °C (milliPas)	
	Samiflex E	CQ70
0.5	20,800	2,560
1.0	13,200	2,000
2.5	7,520	1,408
5.0	4,480	1,056
10.0	2,960	792
20.0	1,960	604
50.0	1,320	440
100.0	–	323

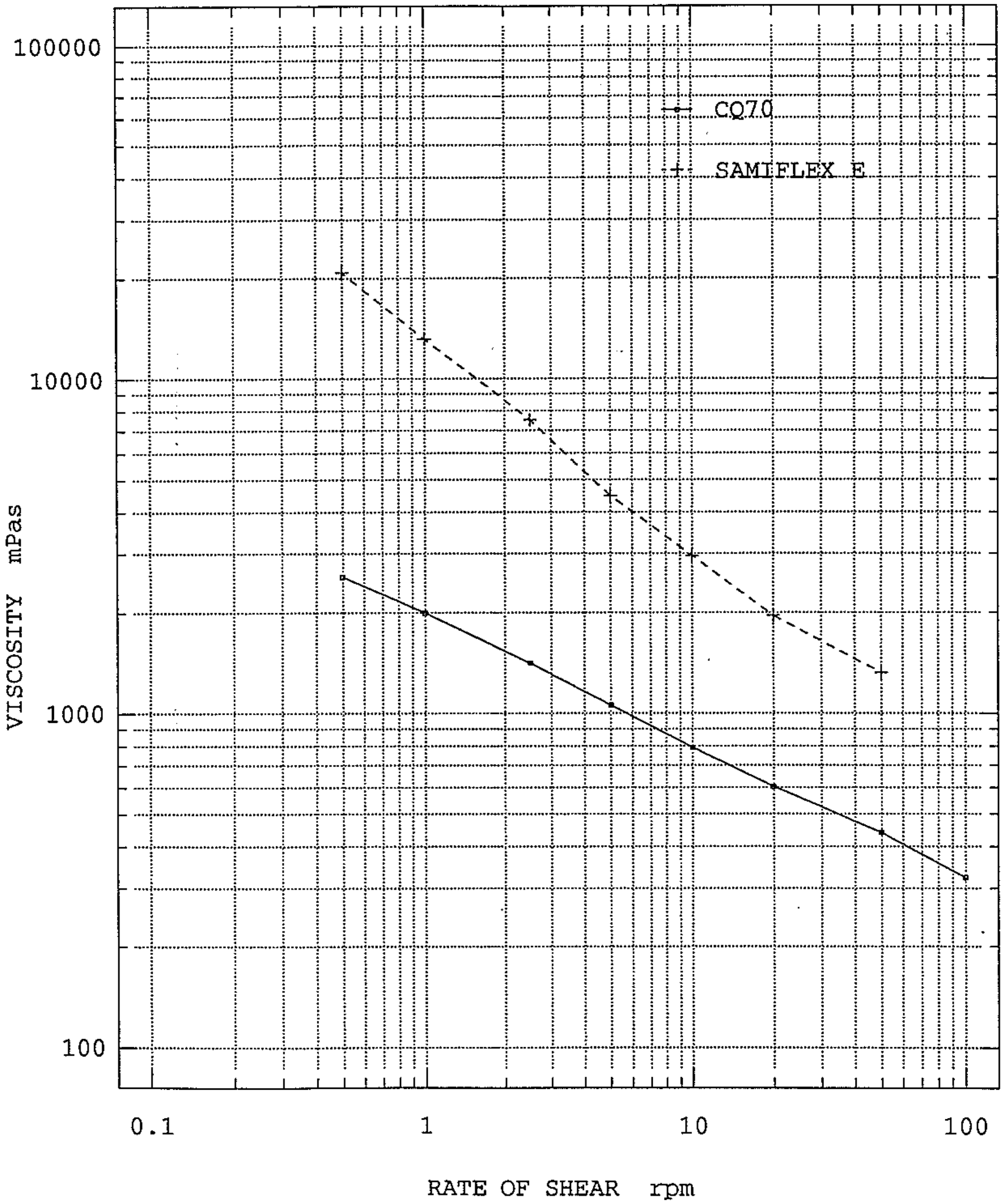
The results are illustrated in Figure 4.1 where the much steeper viscosity shear rate curve of Samiflex E is evident. The shear conditions in a spray nozzle would be much higher than shown in the figure and it is probable that the two curves converge, thus explaining the similarity in spray properties. At low shear, the viscosity of the Samiflex E is approximately 10 times greater than the CQ70, thus explaining the lack of run-off of the emulsion even with relatively high application rates.

The polymer-modified binder was recovered from the emulsion by freezing, to separate the bulk of the water, and then gently warming the binder to remove the last traces of water.

Penetration, softening point and torsional recovery tests performed on the recovered binder gave the following results:

Tests on recovered binder		
Penetration	at 25 °C	114
	at 5 °C	14
Softening Point (°C)		88
Torsional Recovery (25 °C)	at 30 sec	56
	at 30 min	98

Figure 4.1 Comparison of Brookfield viscosities for Samiflex E and CQ70 emulsions.



In addition to the above physical tests, infrared spectra and thermogravimetric analysis were performed.

The infrared data were obtained using an ZnSe ATR cell, 100 scans, 2 cm^{-1} resolution with 30-40 mg deposited from CH_2Cl_2. The results are illustrated in Figure 4.2. Peaks at 699 and 965 are associated with styrene and butadiene respectively. These peaks are absent in bitumens usually used in New Zealand.

Thermogravimetry is used as a method of fingerprinting binders, and the results of rate of weight loss over the temperature range of 35-650°C in air are given in Figure 4.3. Test conditions are 5°C/min temperature rise with an air flow of 200 mm^3/min using a Mettler thermogravimeter instrument.

Results are typical of other binders tested at Opus Central Laboratories. The weight loss peak at 500°C is higher than New Zealand-produced bitumen which peaks at 490°C. This difference is regarded as not significant but illustrates the ability of the technique to differentiate between various bitumen sources.

Figure 4.2 Infrared spectra of recovered Samiflex E binder.

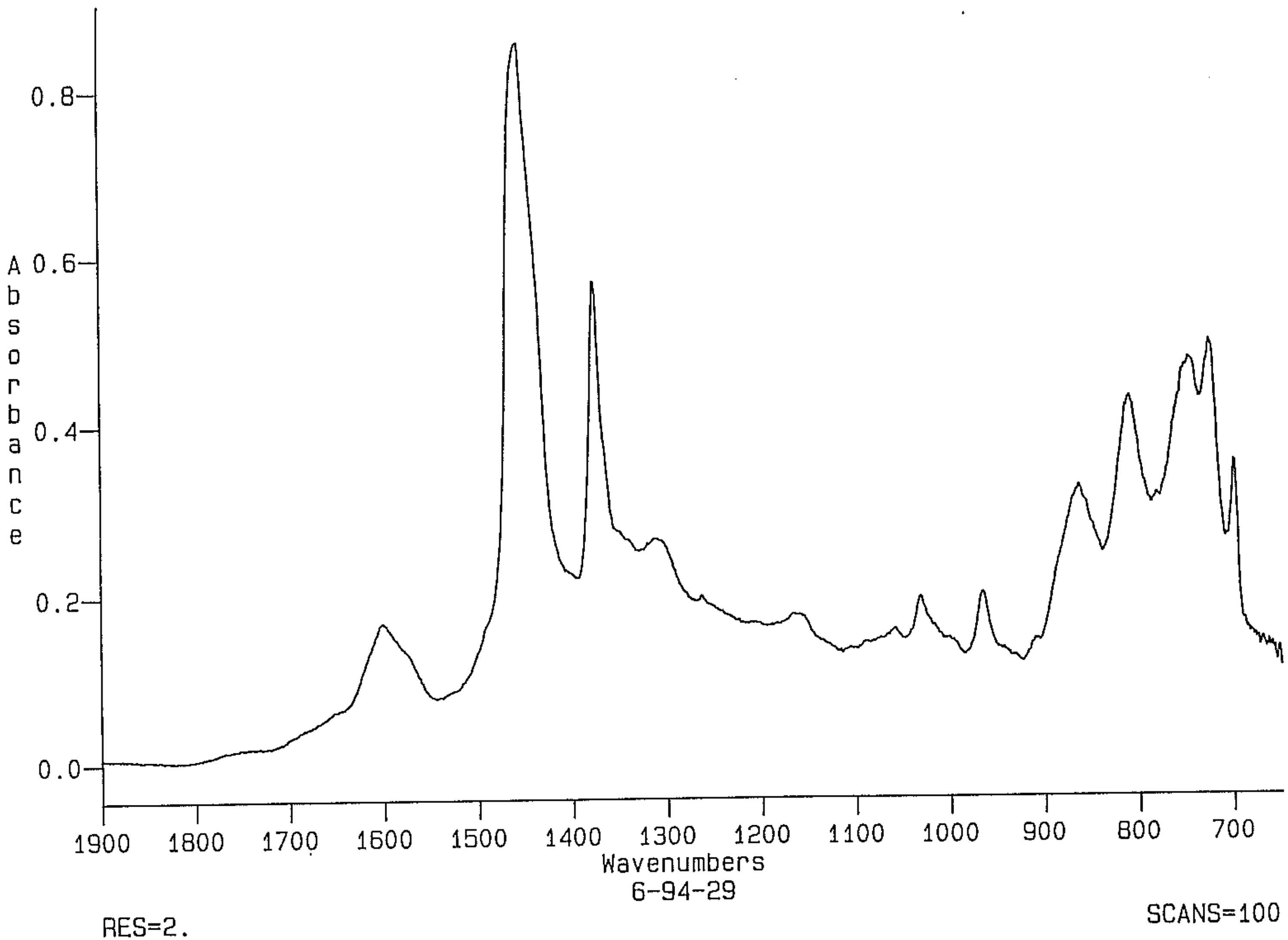
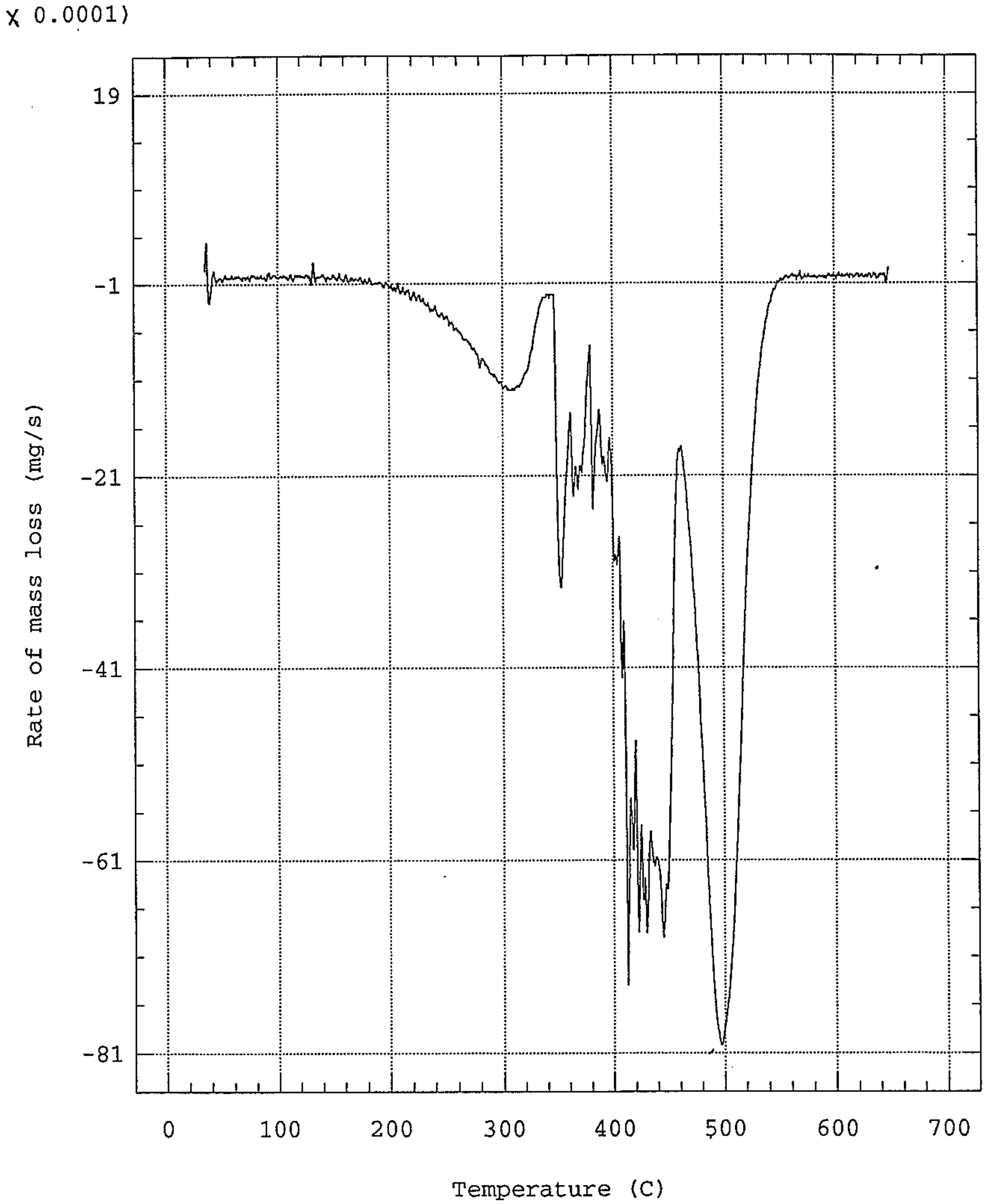


Figure 4.3 Thermogravimetric fingerprint of the recovered Samiflex E binder.



5. Construction Observations

Construction of the trials covered the period December 1993 to the beginning of February 1994. All trials were constructed under good weather conditions with air temperatures between 14°C and 27°C, with pavement temperatures ranging from 16°C to 43°C.

No significant problems were experienced during construction, but the following observations were made:

- The spray properties of the emulsion were not noticeably different from emulsions with 68% binder complying with the TNZ M/1 *Specification for asphaltic bitumen.*
- The thixotropic nature of the emulsion resulted in no run-off into gutters or on grades, even at application rates of 2.5 litres/square metre.
- The racked-in sealing system, with one application of binder followed by two chip sizes, was significantly faster to construct than a traditional two-coat seal.
- On all trials, it took in excess of 1½ hours after spraying for the water to be removed from the seal.
- Controlled traffic could be allowed on the seal within 15 minutes of spraying, i.e. after completion of initial rolling.
- Hand spraying did not cause any difficulties.

6. Performance

In high stress areas the two critical times in the early seal life when failure can occur are:
1. the initial week as the seal beds down, and
2. during the following winter when chip loss can occur.

A summary of the observations at three months and one year are given in Table 6.1. Texture measurements, obtained by using the sand circle test, are given in Table 6.2.

The sites at which chip loss caused by traffic stress has occurred are the two roundabouts, both subjected to significant numbers of heavy vehicles, and Crawford Road in Wellington.

Both roundabouts showed similar chip loss patterns. Figure 6.1 illustrates the extent of distress at the Auckland roundabout after one year. Figure 6.2 gives an overview of the Newlands roundabout, and Figure 6.3 shows the type of distress close to the centre island after one month. This chip loss tended to progress over 12 months.

On Crawford Road, one area shaded by trees developed chip loss within days of construction, even though the area was subjected to lower stresses than some other areas that retained chip. It is suspected that the chip loss in this area would have been prevented if a slightly higher binder application rate had been used.

Crawford Road consists of a number of bends on a gradient of approximately 10%, with a number of intersecting roads. Traffic turning from one intersecting road is shown in Figure 6.4. This very tight bend has withstood the traffic stresses, as has the other road junctions. Other bends subject to faster traffic speeds have suffered chip loss, as illustrated in Figure 6.5, which gives an overview of the bend, and in Figure 6.6 (a,b), which illustrate chip loss on the wheeltracks on the inside of the bend on the uphill and downhill lanes respectively.

Over the monitoring period the area of chip loss did increase but not to the extent that safety was compromised.

Table 6.1 Performance of seals at all trial sites and control sites.

Location	Site	Comments	
		3 months	12 months
New Plymouth	Waiwhakaiho Hill	Excellent condition, slight flushing over previously flushed areas.	Little change, flushed areas have become more prominent.
	Crematorium Hill	Slight flushing in wheeltracks of uphill lane.	Flushing in wheeltracks of uphill slow lane. Flushing in downhill outer wheeltrack.
Auckland	Coronation Road	Excellent condition.	Good condition. Some minor chip loss in overlap of spray run.
	Hastie Avenue	Slight flushing at industrial crossing but no chip loss.	Minor chip loss at industrial crossings.
	Lambie/Cavendish Roundabout	Some chip loss and rollover on inside wheeltrack, less than 5% of area.	Initial chip loss has progressed but only in areas where initial loss occurred.
Wellington	Newlands Roundabout	Slight flushing in hand-spray areas. Scabbing on inside wheeltrack close to centre island. Most of area in good condition.	Chip loss expanded slightly.
	Crawford Road	Chip loss on inside of bends with higher traffic speeds. Major intersections in excellent condition. Control two-coat seal in good condition.	Chip loss on inside of bends was more extensive. Major intersections still in excellent condition. Control two-coat seal in excellent condition.
Christchurch	Porters Pass	Samiflex in excellent condition, control two-coat seal in excellent condition.	No significant change.

7. Conclusions

This joint-funded Transit New Zealand–industry project has demonstrated the construction advantages of the Samiflex E sealing system. Although some sites have shown chip loss, this occurred within the first week of construction. If repairs had been performed at that time, it is considered that all sites would have remained in a good condition.

Advantages of the system that are evident from this trial are:

- The ability to apply high emulsion application rates without run-off.
- The ability to construct the system over a very variable surface texture.
- The reduced risk of polymer degradation related to the low storage and application temperatures.
- The excellent adhesion obtained between the sealing chip and the binder.

At this stage the only improvement that could be made is in the rate of break of the emulsion which, for these trials, was up to 5 hours. However, this can partly be explained because the product had to be stable enough to be transported from Australia. As the emulsion is now manufactured in New Zealand (Eco SEAL), this property should be able to be adapted to New Zealand conditions.

In general, these trials have successfully demonstrated that the system is applicable to New Zealand roads, although the control sections using a two-coat seal with 180/200 grade bitumen have also performed well.

These trials have shown that in very high stressed areas, such as roundabouts, a sealing system may need to be completed in two phases. After the initial construction some areas of chip loss can occur, but if these are repaired within a short time, further early life chip loss is unlikely to continue.

The Samiflex E sealing system is considered to be a lower failure risk treatment than seals constructed with hot applied polymer-modified binder, and thus is a viable alternative surfacing treatment for use on New Zealand roads.

8. References

AUSTROADS. 1997. Framework specification for SBS polymer-modified bitumens. *APRG 19.*

British Institute of Standards. 1984. Specification for bitumen road emulsions. *BS 434, Part 1, Appendix F : 1984.*

Transit New Zealand. 1989. Specification for asphaltic bitumens. *TNZ M/1:1989.*

Table 6.2 Texture measurements obtained from sand circle tests for all trial sites and control sites.

New Plymouth, Crematorium Hill (chip grades 4/6), at 3, 9 and 15 months

Site	Binder application rate (l/m²)	Average sand circle diameter (mm)		
		17/3/94	13/9/94	27/3/95
Southbound slow lane				
30 - 60	1.25	208	208	245
90 - 200	1.4	-	215	255
200 - 250	1.5	195	198	243
Southbound passing lane				
30 - 60	1.4	148	155	153
90 - 200	1.6	-	155	150
200 - 250	1.7	187	178	205
Northbound lane				
30 - 60	1.3	150	168	165
90 - 200	1.5	-	155	155
200 - 250	1.6	198	188	223

Porters Pass (chip grades 3/5), at 1 and 13 months

Site	Binder application rate (l/m²)	Average sand circle diameter (mm)	
		25/2/94	14/2/95
PMB	2.2	123	137
Two-coat seal (control)	N/A	131	137

Crawford Road (chip grades 3/5), at 3 and 13 months

Site	Binder application rate (l/m²)	Average sand circle diameter (mm)	
		22/4/94	22/3/95
1	2.2	173	174
2	2.2	164	174
3	2.2	163	178
Control	2.3	182	190

Table 6.2 (continued)

Newlands Roundabout (chip grades 3/5), at 3 and 14 months

Site	Binder application rate (l/m^2)	Average sand circle diameter (mm)	
		22/4/94	22/3/95
1	2.2	165	208
2	2.2	205	220
3	2.2	148	170
4	2.2	230	230
5	2.2	192	125

Figure 6.1
Distress after one year at Lambie/Cavendish roundabout, Auckland.

Figure 6.2 Newlands roundabout, Wellington.

Figure 6.3 Distress near centre of roundabout, after one month, at Newlands site.

Figure 6.4 This bend on Crawford Road, Wellington, showed no traffic-related distress after one month.

Figure 6.5 Overview of the Crawford Road bend, Wellington.

Figure 6.6 Detail of distress on inside bend of Crawford Road, Wellington, after one month.
a. Uphill lane **b. Downhill lane**

Figure 6.4 This bend on Crawford Road, Wellington, showed no traffic-related distress after one month.

Figure 6.5 Overview of the Crawford Road bend, Wellington.

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