

Long-Life Western Australian Seal Coat

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In Western Australia sprayed seals, laid on thin unbound granular bases, typically have lives of 16 years before a reseal is needed. This type of cheap pavement, using naturally occurring materials, should be ideal for the long lengths of low-volume roads found in the United States. A case history of a seal laid as part of an asphalt cement durability experiment is presented. Extensive data on construction and performance are thus available for this seal, which is typical of hundreds of kilometers of road on either side of the experiment that are giving the same performance and that were laid to the same construction standards and with essentially the same materials. A sand primer seal was first placed on a base consisting of 160 mm unbound, naturally occurring gravel laid over a compacted natural clay sand subgrade. The primer seal was trafficked for 6 months and then the final seal applied. This consisted of Class 160 (85/100 pen) asphalt sprayed at rates varying from 1.3 to 1.6 L/m² and covered with 14-mm one size aggregate, spread one stone thick at a rate of 80 m²/m³. The site is in an area of low rainfall but high summer temperatures. Traffic at the site is low (100 to 200 veh/day—total both directions) but with regular heavily loaded road trains. Pavement deflections were measured using a Benkelman beam and typically were of the order of 0.3 mm. The sections have been inspected every year and are in excellent condition 13 years after construction, with the exception of one section laid with a low-durability asphalt. This performance is typical of seal coats in Western Australia that are commonly used as surfacings on roads carrying in excess of 1,000 veh/day and not infrequently on roads carrying as much as 15,000 veh/day (total both directions). The factors contributing to long seal life are the use of durable asphalts, the seal design procedure, and the construction practices used.

The state of Western Australia has an area of 2,525,000 km² (nearly four times the size of Texas), a population of about 1,700,000, and a sealed road network with a total length of about 40,000 km. The provision of a bituminous all-weather surfacing on a road network that has to serve such a large and sparsely populated area has meant that low-cost sprayed seals have had to be widely used.

Considerable effort has been expended refining design, materials selection, and construction techniques to ensure these seals are not only low cost, but also extremely durable.

The case history of a section of seal laid as part of an asphalt cement durability experiment is presented. The seal is typical of hundreds of kilometers of road on either side of the section that were laid to the same standard using essentially the same materials and that are giving the same performance. The availability of a detailed construction history and performance evaluation gives an insight into the factors that result in average seal lives of 16 years in Western Australia.

Details of the pavement used, primer sealing and sealing techniques, material properties, and in-service performance evaluations, including changes in binder viscosity and its relationship with laboratory-predicted hardening, are presented. The importance of seal design, materials selection, and proper construction techniques in achieving long seal lives is demonstrated.

BACKGROUND

The Australian Road Research Board (ARRB) Durability Test was developed to measure the intrinsic resistance of an asphalt cement to thermal oxidation hardening. In the test, a 20- μ m film of asphalt cement is deposited onto the walls of glass bottles, and these are exposed in a special oven at 100°C. Bottles are withdrawn periodically, the asphalt is removed, and its viscosity measured at 45°C. The durability of the asphalt is the time in days for it to reach an apparent viscosity of 5.7 log Pa.s. Full details of the method are given in an Australian Standard (1).

ARRB proposed a series of national sealing trials to compare the field performance of a number of asphalt cements with different laboratory-predicted durabilities (2). These trials were laid at various sites around Australia and covered a wide range of climatic conditions.

The main trial in Western Australia was placed by the Main Roads Department in 1977 and involved the application of sprayed seals using eight asphalt cements, three different cover aggregates, and a number of cut and fluxed binders. The trial has been regularly monitored to assess performance and to follow binder hardening.

Although the 23 trial sections constructed are each only from 300 to 450 m in length, they are representative of hundreds of kilometers of similar surfacings either side of the trial location. In a more general sense they are similar to most of the rest of the Western Australian rural sealed road networks in terms of pavement type and construction, primer seal treatment, and seal design and construction techniques.

A typical road in the network consists of a selected, naturally occurring granular base that is well compacted and finished to provide a structurally sound properly drained pavement. The pavement is usually primer sealed by spraying with a cutback asphalt cement and covering with a local clean sand. This temporary surfacing is trafficked for a period of from 6 to 12 months before the final sprayed seal surfacing is applied. The latter involves spraying asphalt cement at a designed application rate, then spreading one sized aggregate in a one-stone-thick layer, and rolling to give a stable, skid-resistant, waterproof mat.

This type of construction is used on rural roads carrying from 100 to 5,000 vehicles per day (total both directions) and

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on some urban highways carrying in excess of 15,000 vehicles per day.

SITE DETAILS

The trial sections were laid on a relatively flat, straight section of a sound, newly constructed pavement on the Great Northern Highway near the rural location of Kumarina, about 1,000 km from the capital, Perth.

The Great Northern Highway runs from Perth, in the south, some 3,000 km through the outback of Western Australia to Wyndham, in the north.

The trial site lies in a semiarid area with an annual rainfall of about 200 mm. Temperatures range from about 45°C in summer to about 2°C in winter. The yearly mean of the daily maximum air temperature is 28.6°C, and the mean of the daily minimum temperature for the coldest month (July) is 7.3°C.

Traffic counts indicated an average of between 100 and 200 vehicles per day (total both directions) with about 10 percent heavy vehicles including road trains.

The pavement on which the trials were laid consisted of a 160-mm-thick base of selected unbound naturally occurring gravel laid over a compacted natural clay sand subgrade. The formation was generally slightly raised and well drained. Benkelman beam test results of the order of 0.3 mm maximum deflection were measured throughout.

The pavement was primer sealed over the period May to June 1977. The binder used was an 80/17/3 blend of asphalt cement (85/100 penetration), kerosene, and distillate, and this was applied at 1.4 L/m² (hot) and covered with a coarse river-washed sand.

This treatment fulfilled a dual role in that it acted both as a prime coat, by penetrating the surface voids and bonding to the base, and also as a seal by providing an effective,

although temporary, waterproof bituminous running surface. Provided the binder composition and application rate are designed to suit the traffic condition and cover material available, good performance can be readily achieved using this technique.

TRIAL DETAILS

Binder Supplies

A total of eight asphalts were used in the sealing trials. Details are given in Tables 1 and 2. The asphalts were supplied hot (160°C–180°C) and in bulk to the trial site using previously cleaned delivery vessels to avoid contamination and problems of nozzle blockage during spraying. The asphalt included normal local supplies plus a number of imported products to give a wide range of predicted durabilities. A range of cutters and fluxes was also supplied for on-site blending as required for some trial sections. In addition, a proprietary brand of anti-stripping additive was provided for inclusion in the binder in all trial sections at a dosage rate of 0.3 percent by mass of the binder.

Aggregate Supplies

Three cover aggregates were used in the trial sections to investigate the effect of light reflection on the durability of asphalt cement. The main trials used a gray metabasalt, whereas a light granite and a dark brown crushed river shingle were used on other sections to provide contrasting reflectance. Details of the aggregates are given in Table 3. All aggregates were lightly precoated with distillate before use to prevent adhesion problems due to dust.

TABLE 1 DETAILS OF ASPHALTIC CEMENTS USED

Asphaltic Cement	Road Section Numbers	Class (AS2008)	Crude Oil Source	Refinery	Processing
1	1 to 8	160	Kuwait	Kwinana	Vacuum reduced and blown to grade
2	9	80	Kuwait	Kwinana	Vacuum reduced and blown to grade
3	10	80	Kuwait	Fremantle	Diluted vacuum residue topped and blown to grade
4	11	160	Light Arabian	Singapore	Soft blend of vacuum residue with PPA ^a blown to grade
5	12, 23	160	Kuwait	Singapore (via Port Hedland)	Vacuum reduced and blown to grade
6	13	160	Light Arabian	Singapore	Blend of vacuum residue with PPA ^a
7	14	160	Basrah	Kwinana	Vacuum reduced and blown to grade
8	15 to 22	160	Kuwait	Fremantle	Diluted vacuum residue topped and blown to grade

^a PPA = Propane precipitated asphalt from soft residue

TABLE 2 STANDARD TEST RESULTS ON BASE ASPHALTIC CEMENTS

Asphaltic Cement	1	2	3	4	5	6	7	8
Viscosity at 60°C (Pa.s)	166	43.7	29.9	147	185	94	135	157
Viscosity at 135°C (Pa.s)	0.41	0.22	0.19	0.36	0.41	0.29	0.34	0.43
Pen at 15°C (200 g 60 s), (mm)	11.9	33.1	>40	10.9	10.6	16.1	13.0	13.4
Density at 25°C (kg/L)	1.023	1.017	1.009	1.028	1.025	1.029	1.017	1.019
Flashpoint (°C)	312	286	207	344	335	352	324	271
Solubility in Trichloroethylene(% mass)	100	100	100	100	100	100	99.9	99.9
Effect of heat and air (RFOT)								
(a) Ductility of residue at 15°C (mm)	700	>1000	>1000	670	190	>1000	510	330
(b) Viscosity of residue at 60°C as % of original	200	199	313	230	273	235	207	266
ARRB Durability Test Result (days)	9.0	19.0	10.0	11.0	6.5	18.0	12.0	7.0

Binder Application Rate Design

The National Association of Australian State Road Authorities design method (3) was used as a basis for the design of binder application rates with appropriate adjustments for site conditions. This design method assumes that the aggregate particles, after rolling and compaction by traffic, will lie close packed as a single layer with their least dimensions vertical, and that the average thickness of this layer will be the average least dimension (4) of the aggregate. The void content of the layer is assumed to be 20 percent. The quantity of binder required to fill the desired proportion of these voids is calculated taking into account predicted traffic. Adjustments may be made to allow for embedment of the seal aggregate into the substrate, binder absorption, and other factors. The design binder application rates for the trial are given in Table 4.

TABLE 3 SOURCE, ROCK TYPE, AND PROPERTIES OF THE AGGREGATES

Rock Type	Metamorphosed Basalt	Granite	Partly Crushed Gravel
Source	Noonyerina Quarry	Tukanarra Quarry	Local River Shingle
Colour	Light Grey	Grey/white Mottled	Reddish Brown
GRADING % mass passing AS sieve (mm)			
19.0	-	-	100
16.0	100	100	99
13.2	87	83	95
9.5	14	15	7
6.7	1	1	0.5
4.75	0.3	0.2	0.1
Flakiness Index	22	18	26
ALD (mm)	8.5	9.1	8.2

TABLE 4 DESIGN AND ACTUAL BINDER APPLICATION RATES

Aggregate	Design Application Rate of Residual Binder (L/m ²)	Mean Achieved Application Rate of Residual Binder (L/m ²)
Meta-basalt	1.40	1.42
Granite	1.53	1.56
River Shingle	1.35	1.40

Construction Details

A total of 23 trial sections were sprayed, as given in Table 5. Maximum shade air temperatures were up to 41°C, and except for a period of 1 day, no rain fell. Conditions were thus ideal for sealing. The road was sealed to a total width of 7.4 m in two half-width spray runs using a certified calibrated distributor (3). Distributor volume was measured after each spray run and binder application rates checked for each area sprayed. Average rates of application for each aggregate type are given in Table 4. Each spray run was started and finished on spray paper to obtain accurate cutoffs. A constant distributor speed was maintained to ensure uniformity of application. Spray runs were aligned against marked pavement guides and correct overlap of the longitudinal part of the two spray runs ensured by this alignment and nozzle overlap.

Aggregate was spread from trucks fitted with simple control gates, and gate-opening and truck speed was regulated to give correct aggregate spread rates and a one-stone-thick aggregate layer. Rolling to embed and align the aggregate was carried out with a combination of steel and rubber tire rollers. Back brooming to redistribute and realign any misspread aggregate was also carried out.

The complete sequence of operations was executed by an experienced crew with careful attention to detail to ensure a

TABLE 5 SECTION DETAILS

Section No	Asphalt No.	Durability (days)	Binder Blend	Aggregate
1	1	9.0	No cutter or flux	Metabasalt
2	1	9.0	No cutter or flux	Granite
3	1	9.0	No cutter or flux	River Shingle
4	1	9.0	3% Distillate	Metabasalt
5	1	9.0	3% Diesel Fuel Oil	Metabasalt
6	1	9.0	4% Furnace Oil (F60)	Metabasalt
7	1	9.0	5% Mineral Turpentine	Metabasalt
8	1	9.0	5% Avialon Turbine Kero	Metabasalt
9	2	19.0	No cutter or flux	Metabasalt
10	3	10.0	No cutter or flux	Metabasalt
11	4	11.0	No cutter or flux	Metabasalt
12	5	6.5	No cutter or flux	Metabasalt
13	6	18.0	No cutter or flux	Metabasalt
14	7	12.0	No cutter or flux	Metabasalt
15	8	7.0	No cutter or flux	Metabasalt
16	8	7.0	No cutter or flux	Granite
17	8	7.0	No cutter or flux	River Shingle
18	8	7.0	3% Diesel Fuel Oil	Metabasalt
19	8	7.0	3% Distillate	Metabasalt
20	8	7.0	4% Furnace Oil (F60)	Metabasalt
21	8	7.0	5% Mineral Turpentine	Metabasalt
22	8	7.0	5% Avialon Turbine Kero	Metabasalt
23	5	6.5	No cutter or flux	Metabasalt

TABLE 6 VISCOSITY OF RECOVERED BINDER

Construction Information				Viscosity of Recovered Binder 45°C & 5 x 10 ⁻³ s ⁻¹ (log Pa.s)						
Section No	Asphalt No	Aggregate	Durability (day)	After 2 Yrs 1979	After 4 Yrs 1981	After 6 Yrs 1983	After 8 Yrs 1985	After 9 Yrs 1986	After 11 Yrs 1988	After 13 Yrs 1990
1	1	Basalt	9.0	4.53	5.07	5.34	5.78	6.00	6.36	6.40
2	1	Granite	9.0		5.25	5.47		6.06	6.82	6.77
3	1	Shingle	9.0		5.73	5.97		6.46	7.13	7.22
4	1	Basalt	9.0		5.19	5.47	5.88	5.83	6.23	6.59
5	1	Basalt	9.0		5.11	5.42	5.92	5.90	6.32	6.80
6	1	Basalt	9.0		5.21	5.57	6.16	6.09	6.56	7.03
7	1	Basalt	9.0	4.71	5.08	5.57	5.85	6.20	6.44	6.57
8	1	Basalt	9.0	4.83	5.25	5.70	6.12	6.06	6.38	7.06
9	2	Basalt	19.0	4.26	4.81	5.10		5.99	6.32	6.64
10	3	Basalt	10.0	4.45	4.92	5.21		6.16	6.46	6.72
11	4	Basalt	11.0	4.57	5.02	5.54		5.88	6.33	6.31
12	5	Basalt	6.5	4.83	5.30	5.66		6.32	6.73	7.10
13	6	Basalt	18.0	4.43	4.72	5.25		5.62	5.89	6.39
14	7	Basalt	12.0	4.77	5.13	5.56		6.14	6.52	6.50
15	8	Basalt	7.0	4.95	5.58	6.03	6.38	6.63	6.74	6.97
16	8	Granite	7.0		5.61	5.76		6.80	6.92	7.22
17	8	Shingle	7.0		6.09	6.22		6.96	7.16	7.62
18	8	Basalt	7.0		5.18	5.68	6.20	6.15	6.44	7.07
19	8	Basalt	7.0		5.44	5.67	6.18	6.27	6.86	6.96
20	8	Basalt	7.0		5.22	5.66	6.40	6.45	6.68	6.91
21	8	Basalt	7.0	4.88	5.39	5.89	6.28	6.46	6.79	7.02
22	8	Basalt	7.0	4.92	5.52	5.84	6.25	6.51	6.54	6.98
23	5	Basalt	6.5		5.27	5.45		6.20	6.54	7.04

sound job and a stable seal mat at the completion of each day's work.

MONITORING

The trial sections have been regularly monitored since spraying. The monitoring has included sampling areas of seal for recovery of binder and measurement of its viscosity, as well as inspection and recording of seal condition. The results of binder viscosity measurements are given in Table 6. The results of the most recent field inspection, which rates performance on the basis of stone retention, surface texture, and cracking is given in Figure 1. These parameters were selected as providing the most effective indicators of incipient distress due to binder embrittlement.

DISCUSSION OF RESULTS

The performance of all trial sections in providing an effective abrasion and skid-resistant waterproof surfacing over the 13-

year service period to date has been excellent. Although a large number of factors can influence seal performance, where a durable aggregate has been used and the pavement remains sound, the life of a properly designed and constructed seal depends largely on the life of the binder. The binder will oxidize and harden with time until it can no longer withstand the movements caused by diurnal temperature changes or flexure under vehicle loads. Cracking then occurs, or the bond between the aggregate and binder fractures (5).

As can be seen in Figure 1, all sections still show excellent stone retention and, with few exceptions, limited or no cracking and good surface texture. The first two parameters are good indicators of binder distress and demonstrate the generally satisfactory performance of the seals from this viewpoint.

A closer examination of Figure 1 in conjunction with Table 6 indicates the relationship between binder hardening and seal performance. The only section showing significant signs of cracking is Section 17, which has the hardest binder. Significant cracking first appeared in 1990 when a binder viscosity of 7.62 log Pas was measured.

Using this viscosity as an indicator of terminal condition and extrapolating the test results enables seal lives to be pre-

SECTION		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
STONE RETENTION	Good Even Carpet	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
	Odd Stones Lost (1% min)			X														X						
	Minor Stripping																							
	Major Loss, Bare Areas																							
SURFACE TEXTURE	Stones Well Proud of Binder	X			X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
	Stones Just Proud of Binder	X	X	X	X					X			X	X	X			X	X			X	X	X
	Binder Flush With Stone		X																					
	Fatty Patches																							
CRACKING	Large Fatty Areas																							
	No Cracks	X	X	X	X		X	X	X	X		X	X	X	X	X			X	X	X	X	X	
	Few fine Cracks - Edge					X					X							X	X					X
	Block Cracking																	X						
	Large Cracks - Edge																							

FIGURE 1 Kumarina trial inspection report, June 1991.

dicted for other sections. Thus, sections with more durable binders can be estimated to have potential lives of more than 20 years.

Table 6 can also be used to relate laboratory-predicted durability to in-service hardening. There is a general trend, when variables such as aggregate type and the use of cutters or fluxes are taken into consideration, for the most durable bitumens to show the least hardening. A number of sections from this trial were regularly sampled and tested by ARRB and form part of the data base of road trials around Australia used to develop an asphalt hardening model described by Oliver (5), which relates rate of binder hardening in a seal to the average temperature at the site and the durability of the asphalt cement used. The results of all trials taken together have indicated that the ARRB durability test appears to provide a reasonable indication of field durability (6).

Examination of the viscosity results of those trial sections incorporating cutters or fluxes shows no obvious trends, due to these products, that could not be explained by statistical scatter.

Bitumen durability is the critical determinant of seal life only where the initial design and construction has been sound and premature distress does not occur. As indicated earlier, the importance of proper design of binder application rates to provide enough asphalt cement to hold the cover aggregate in place, yet provide sufficient surface texture to provide skid resistance and avoid bleeding, is well recognized in Western Australia. Refinement of the design procedure continues to receive considerable priority in Australia, and a national working party is currently addressing the subject.

Examination of the design and applied binder application rates in Table 4 indicates that the design rates were substantially achieved in practice and resulted in good performance, as indicated in Figure 1. The only exception to this observation relates to sections where the surfacing received excessive steel wheel rolling at construction and the softer granite aggregate was crushed.

This emphasizes the importance of construction techniques in achieving optimum seal performance. These techniques start with proper base course materials selection and preparation and provision of adequate drainage to ensure a structurally sound pavement. The application of a primer seal provides an additional waterproof layer to augment the final seal and minimize the effect of absorption of the seal binder by the base. It also provides a uniform, dense surface on which to apply the seal coat. The uniformity simplifies seal design and application.

Application of the design binder rate uniformly, in both a transverse and a longitudinal direction, must then be addressed. For this reason distributors must be calibrated and certified in accordance with national guidelines (7) and operated by experienced crew. It is also important that the asphalt cement not be degraded by overheating, temperature gauges fitted to the distributors, and storage vessels regularly monitored.

Finally, aggregate must be uniformly spread in a one-stone-thick layer and rolled and broomed to embed and align the

stone to form a dense stable mat. Distribution of the aggregate can be achieved with simple spreading equipment provided experienced operators are employed, as was the case on this project. Rolling may commence with steel wheeled rollers to give initial embedment. However, overrolling must be avoided and the bulk of compaction achieved with rubber tire rollers that prevent bridging and crushing.

CONCLUSIONS

Sprayed seals can provide an excellent, economic, and durable bituminous surfacing for use on both rural and urban roads. Although the project described in this paper related to a low traffic volume road and was only 13 years old, it was still performing well, and such surfacings give an average life span of 16 years in Western Australia and are used on roads carrying up to 15,000 vehicles per day (total both directions).

For this type of performance to be reliably achieved, the seal must be properly designed and constructed on a sound pavement. Key factors contributing to a long seal life include use of a sound design procedure, durable asphalt cement, and high-quality construction techniques with careful attention to detail to ensure uniform application.

ACKNOWLEDGMENT

This paper is presented with the permission of the Commissioner of Main Roads, Western Australia, and the Executive Director of the Australian Road Research Board.

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The views expressed in the paper are solely those of the authors.

Publication of this paper sponsored by Section on Bituminous.