Epoxy modified open-graded porous asphalt

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Economic evaluation of long-life pavements:
Phase II, Design and testing of long-life wearing courses

P. Herrington, D. Alabaster, G. Arnold, S. Cook, A. Fussell and S. Reilly

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PO Box 2840, Waterloo Quay, Wellington, New Zealand
Telephone 64-4 931 8700; Facsimile 64-4 931 8701
Email: *research@landtransport.govt.nz*
Website: *www.landtransport.govt.nz*

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[1]Opus International Consultants, Central Laboratories, PO Box 30 845, Lower Hutt
[2]Transit New Zealand, PO Box 1479, Christchurch
[3]Pavespec Ltd, 26 Copeland St, Lower Hutt

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Contents

Executive summary

This research formed the New Zealand contribution to a larger collaborative research programme being carried out under the auspices of the OECD/ECMT (European Conference of Ministers of Transport) Joint Transport Research Centre: Economic evaluation of long-life pavements: Phase II, Design and testing of long-life wearing courses. The aim of the research was to investigate the performance of epoxy modified asphalt (of various designs) and an especially formulated thin cementitious material. These surfacing materials offer the possibility of very long lifetimes (>30 years) with essentially no maintenance required. Key roading research organisations and agencies from a number of countries participating in the programme included: TRL, UK Highways Agency (United Kingdom), Turner-Fairbank Highway Research Center (USA), LCPC (France), BASt (Germany), DRI (Denmark), IBDiM (Poland) and the State Road Scientific Research Institute (Ukraine). Results and conclusions from the complete OECD project are to be published in 2007.

The New Zealand contribution to the research focused on the potential benefits of epoxy modified open-graded porous asphalt (OGPA). Laboratory investigations were undertaken into the cohesive properties of OGPA manufactured using epoxy modified bitumen and an associated accelerated loading test was carried out at Transit New Zealand's Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF) to demonstrate the technology.

Binder oxidation is the principal factor governing the ultimate life of porous asphalt. Because of the very open nature of the material, oxidation and binder embrittlement is more rapid than in dense mixes. Oxidative hardening ultimately leads to failure of the mix through loss of material from the surface (ravelling or fretting) under traffic shearing stresses. The result is a rough uneven riding surface. The short average lifetime in New Zealand of 10 to 11 years for porous asphalts (in many cases only seven to eight years), compared with that of dense mixes (about 16 years), adversely affects their benefit-cost ratios and thus inhibits the more widespread use of this safe and environmentally friendly surfacing.

The purpose of this investigation was to determine the effect of epoxy modified bitumen on the cohesive properties (and hence probable resistance to fretting and ravelling) of OGPA. Additionally a limited accelerated loading trial was undertaken, primarily as a demonstration project, to assess potential practical difficulties associated with full-scale manufacture and construction of epoxy modified asphalt mixtures.

Laboratory study

Materials and methods

The epoxy bitumen (supplied courtesy of ChemCo Systems Ltd, California) is a two-part product blended just before use. The product is free from solvents. The bitumen used for the control mixtures was a standard (TNZ M/1) 80/100 penetration grade bitumen commonly used in OGPA surfacings in New Zealand. A standard aggregate grading conforming to the TNZ P/11 OGPA specification was used for both the mixtures. Epoxy modified OGPA specimens were cured for 120 hours at 85°C before testing.

Indirect tensile modulus measurements were conducted at 25°C according to AS 2891.13.1. Mixture cohesion was measured using the Cantabro test. In this test, right cylinders of compacted mix are tumbled in a steel drum. The mass of aggregate lost from the specimen through abrasion is recorded as a percentage of the original mass.

To assess resistance to oxidation the control and epoxy specimens were heated at 85°C for 909 hours (38 days) to simulate approximately seven years ageing in the field.

Results

The mean modulus of the cured epoxy specimens was 4300 MPa compared with 840 MPa for the control specimens. The uncured epoxy mixture modulus, 570 MPa, was lower but still comparable to that of the control. After oxidation the epoxy modulus increased to 7000 MPa compared with 4000 MPa for the control.

Cantabro test results are given in Table E1.

Table E1. Summary of Cantabro test results.

	% mass lost(±95% confidence limits)			
Mixture	10°C*		25°C	
	Initial	After oxidation (909 hrs, 85ºC)	Initial	After oxidation (909 hrs, 85ºC)
Epoxy (cured)	14.9 ± 4.6	17.6 ± 4.6	16.2 ± 3.2	13.0 ± 2.7
Control	53.2 ± 5.2	72.1 ± 7.7	16.5 ± 3.0	30.6 ± 4.2

* Carried out using specimens from the accelerated loading trial

Despite the high modulus of the cured epoxy material the Cantabro test results of the unoxidised mixture are comparable to that of the control at 25°C but markedly better at 10°C. After oxidation, mass losses both at 10°C and 25°C are much lower than that of the control. In fact over the range of conditions used, the epoxy specimens were essentially unaffected by temperature or oxidation.

Accelerated loading trial

Construction

A turbulent mass continuous mix drum plant was used to manufacture the epoxy OGPA for an accelerated loading trial at the CAPTIF test facility. The mix design used for the trial was essentially the same as that used in the laboratory study. Manufacture of the epoxy mixture was found to be straightforward and was completed without difficulty.

The trial consisted of adjacent control and epoxy OGPA sections each 6 m long, 2 m wide and 30–35 mm thick. The OGPAs were laid on a 200 mm thick pad of dense graded asphalt. No problems in handling or compaction of the epoxy OGPA were noted; its behaviour and appearance were indistinguishable from that of the control material. No unusual fuming or smell was noted.

Results

The test sections were trafficked for 198,000 wheel passes over a period of about three weeks. Trafficking began when the epoxy OGPA had reached about 60% of full cure. The surface temperature during trafficking averaged 12.1°C.

The epoxy OGPA appeared unaffected by trafficking but the control section, although not extensively damaged, lost a significant amount of chip from the surface at points along the length of the wheel path.

Rutting in the control section increased continually with trafficking while the rutting in the epoxy section stabilised after about 60,000 passes, probably reflecting the fact that the OGPA was only partially cured when trafficking commenced. Under field conditions initial trafficking will be applied to essentially uncured asphalt and early rutting may occur. However (based on the modulus of the uncured epoxy OGPA), this is unlikely to be more severe than that associated with standard asphalt mixtures.

After 198,000 passes the skid resistance of the epoxy section, although still acceptable in practice, had decreased slightly, whereas that of the control site had increased beyond its initial value. The most likely explanation for these results is that the increase in skid resistance of the control section was due to the test results being affected by the surface disruption and abrasion damage observed on the control section.

Conclusions

The Cantabro test is a severe test of mixture cohesion relating to the resistance of an OGPA mixture to surface aggregate abrasion losses (fretting or ravelling) in the field. The test results indicated that, for the epoxy bitumen used in this study, the early life cohesive properties of cured epoxy OGPA should be comparable to that of standard OGPA at 25°C and markedly superior at 10°C. The modulus of the cured epoxy mixture was much higher than that of the standard OGPA but this is probably of little benefit given that failure through rutting and deformation is uncommon for properly designed OGPA.

The superior oxidation resistance of the epoxy material was clearly evident in Cantabro tests conducted at both 25°C and 10°C. As surface ravelling is the principle failure mode for OGPA these results suggest a markedly improved field life for epoxy bitumen OGPA compared to the standard asphalt.

A limited accelerated pavement testing trial using CAPTIF demonstrated that full-scale manufacture and surfacing construction with epoxy OGPA can be easily undertaken without needing any significant modification to plant, machinery or operating procedures. Limited trafficking of the test sections resulted in early signs of surface abrasion in the control section but not in the epoxy, behaviour consistent with that predicted from the Cantabro test results. Early life rutting of epoxy mixtures is not likely to be greater than that of equivalent standard materials but should not detract from their apparent advantages.

Abstract

Investigations into the cohesive properties and oxidation resistance of an acid cured, epoxy modified open-graded porous asphalt (OGPA) were undertaken and an associated accelerated loading test carried out at Transit New Zealand's CAPTIF facility.

Results from the Cantabro test (a test of mixture cohesion relating to the resistance of OGPA to surface abrasion losses) indicated that the early life cohesive properties of cured epoxy OGPA should be comparable to that of standard OGPA at 25°C and markedly superior at 10°C. The modulus of the cured epoxy mixture was much higher than that of the standard OGPA but this is probably of little benefit given that failure through rutting and deformation is uncommon for properly designed OGPA.

The superior oxidation resistance of the epoxy material was clearly evident in Cantabro tests conducted at both 25°C and 10°C. The CAPTIF trial demonstrated that full-scale manufacture and surfacing construction with epoxy OGPA could be easily undertaken without any significant modification to plant or the necessary operating procedures. Trafficking of the test sections resulted in early signs of surface abrasion in the control section but not in the epoxy. Early life rutting of epoxy mixtures is not likely to be greater than that of equivalent standard materials.

1. Background

This research formed the New Zealand contribution to a larger collaborative research programme being carried out under the auspices of the OECD/ECMT (European Conference of Ministers of Transport) Joint Transport Research Centre: Economic evaluation of long-life pavements: Phase II, Design and testing of long-life wearing courses. The aim of the research was to investigate the performance of epoxy modified asphalt (of various designs) and an especially formulated thin cementitious material. These surfacing materials offer the possibility of very long lifetimes (>30 years) with essentially no maintenance required. Key roading research organisations and agencies from a number of countries participating in the programme included: TRL, UK Highways Agency (United Kingdom), Turner-Fairbank Highway Research Center (USA), LCPC (France), BASt (Germany), DRI (Denmark), IBDiM (Poland) and the State Road Scientific Research Institute (Ukraine). Results and conclusions from the complete OECD project are to be published by mid-2007.

The New Zealand contribution to the research focused on the potential benefits of epoxy modified open-graded porous asphalt (OGPA). Laboratory investigations into the cohesive properties of OGPA manufactured using epoxy modified bitumen were undertaken and an associated accelerated loading test was carried out at Transit New Zealand's Canterbury accelerated pavement testing indoor facility (CAPTIF) to demonstrate the technology.

Although the safety and noise reduction properties of OGPA are well documented, binder oxidation remains a major problem and is the principal factor governing the ultimate life of porous asphalt. Because of the very open nature of the material, oxidation and consequent binder embrittlement is more rapid than in conventional mixes. Oxidation ultimately leads to failure of the mix through loss of material from the surface (ravelling or fretting) under traffic shearing stresses. The result is a rough uneven riding surface. The short average lifetime in New Zealand of 10 to 11 years for porous asphalts (in many cases only seven to eight years), compared with that of dense mixes (about 16 years), adversely affects their benefit-cost ratios and thus inhibits the more widespread use of this safe and environmentally friendly surfacing.

The purpose of this investigation was to determine the effect of epoxy modified bitumen on the cohesive properties (and hence probable resistance to fretting and ravelling) of OGPA. Additionally a limited accelerated loading trial was undertaken, primarily as a demonstration project, but also to assess potential practical difficulties associated with full-scale manufacture and construction of epoxy modified asphalt mixtures.

2. Materials

Greywacke aggregates were obtained from Winstone Aggregates Ltd for the initial laboratory investigations. The epoxy bitumen (supplied courtesy of ChemCo Systems Ltd, California) is a two-part product blended just before use. Part A (used at 14.6% by weight) consists of an epoxy resin formed from epichlorhydrin and bisphenol-A. Part B type V (85.4%) consists of a fatty acid curing agent, in an approximately 70 pen bitumen. The product is free from solvents. After full curing has taken place the product is similar in consistency to a hard rubber. The bitumen used for the control mixture was an 80/100 penetration grade bitumen from Middle Eastern crude conforming to the Transit New Zealand TNZ M/1 specification and commonly used in OGPA surfacings in New Zealand.

3. Mixture design and manufacture

The testing programme involved both the epoxy OGPA and a standard OGPA as a control. A standard aggregate grading conforming to the TNZ P/11 OGPA specification was used for both mixtures (see Table 3.1). The bitumen content was 4.7%. Compaction of 100 mm diameter cylindrical specimens was by gyratory compactor, giving air voids of 20.4 ±1.2% (95% confidence limits) for all the specimens used in the study.

The control mixtures were manufactured at a temperature of 125°C. In accordance with the literature supplied by ChemCo Systems Ltd the epoxy bitumen mixtures were made with parts A and B heated to 90°C and 125°C respectively and blended just before addition to the aggregate, held at 125°C. The epoxy bitumen mixtures were held at 125°C for 45 minutes before compaction.

Table 3.1 Grading of aggregate used in epoxy and control mixtures.

Sieve size (mm)	13.2	9.5	6.7	4.75	2.36	0.60	0.075
Passing (%)	100	98	66	36	25	13	6.3

Note: Binder content: 4.7%.

4. Laboratory testing programme

4.1 Indirect tensile modulus (ITM) measurements

ITM measurements were conducted on a 5 kN test frame (Model UTM-5, IPC Australia Ltd) at 25°C according to AS 2891.13.1. This procedure employs a recovered horizontal strain of 50 $\mu\varepsilon$, a rise time (90%) of 0.04 seconds and a pulse repetition of 3.0 seconds. A Poisson's ratio of 0.35 was assumed. The moduli of the uncured or unoxidised specimens were measured within 24 to 48 hours after manufacture. At least five hours (usually overnight) were allowed for specimens to stabilise at the test temperature. The ITM results presented were the mean of at least five and up to 10 replicates with an error (average 95% confidence limit) of ±10%.

4.2 Cantabro test – cohesion measurements

Mixture cohesion was measured using the Cantabro test. The test procedure and detailed specifications for the equipment are given in APRG (1999), which is in turn based on the Los Angeles abrasion test described in AS 1141.234. In this test, right cylinders of compacted mix (100 mm diameter and 50–70 mm high) are brought to a temperature of 25± 0.5 °C in an incubator and then tumbled in a steel drum (maintained at 25 ± 3°C) for 300 revolutions at 30 rpm. The mass of aggregate lost from the specimen through abrasion is recorded as a percentage of the original mass.

Measurements on uncured or unoxidised specimens were made within 24 to 48 hours of manufacture. At least five hours (usually overnight) were allowed for specimens to stabilise at the test temperature. The test machine was enclosed in a large cabinet through which temperature-controlled air from a refrigeration/heating unit was circulated. The Cantabro test equipment and specimens before and after testing are illustrated in Figure 4.1.

The Cantabro test results presented are the mean percentage losses of six to 10 replicates with an error (average 95% confidence limit) of ±4 percentage units.

Figure 4.1 Cantabro test equipment and specimens before and after testing.

5. Results of laboratory testing programme

5.1 Curing

Accelerated curing of the epoxy bitumen specimens for Cantabro testing was carried out at 85°C for 120 hours (following the procedure adopted by other researchers in the project using an equivalent acid curing epoxy material). The effect of curing time on the ITM is shown in Figure 5.1 which shows that the increase in ITM was relatively small above 120 hours (no significant difference at the 95% level) indicating curing was essentially complete.

The ITM of the epoxy bitumen OGPA increased over seven times from 570 immediately after manufacture to 4300 after curing. By comparison the ITM of the control specimens only increased from 840 to 2500 after a comparable period at 85°C.

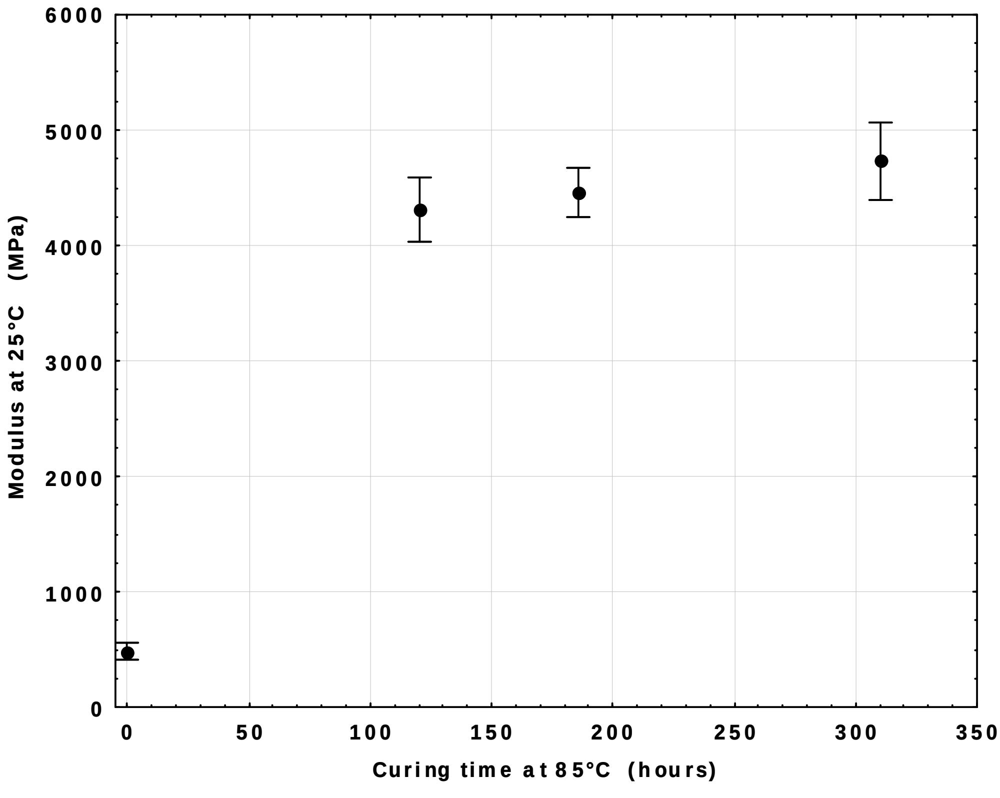

Figure 5.1 Curing time for epoxy bitumen OGPA specimens.

5.2 Cantabro test results

5.2.1 Unoxidised (unaged) specimens

The Cantabro test results are shown in Figure 5.2, as is the ITM data. Data for epoxy bitumen cured for 310 hours are also presented for comparison. It can be seen that the losses from the control and cured epoxy OGPA were equivalent, which was somewhat unexpected given the much higher modulus values of the epoxy specimens.

5.2.2 Oxidised specimens

The control and epoxy specimens were heated at 85°C for 909 hours (38 days) to simulate oxidation in the field. A control specimen was extracted with dichloromethane and the viscosity of the recovered bitumen measured and compared with data previously obtained on field samples of aged OGPA surfacings in New Zealand (Herrington et al. 2005). On this basis the 909 hour oven treatment was estimated as being approximately equivalent to seven years ageing in the field.

The results of the Cantabro testing on the oxidised specimens are shown in Figure 5.3. It can be seen that the ITM of the epoxy OGPA increased by 1.6 times compared with a 4.8-fold increase for the control. More significantly, the mass loss of the control specimens almost doubled whereas that of the epoxy bitumen specimens actually decreased slightly (16.2% to 13%). When the 15% Cantabro test losses for the 310 hour cured epoxy OGPA (Figure 5.2) are considered there was a downward trend in mass loss as curing/oxidation time increased. However, the data were not significantly different at the 95% level.

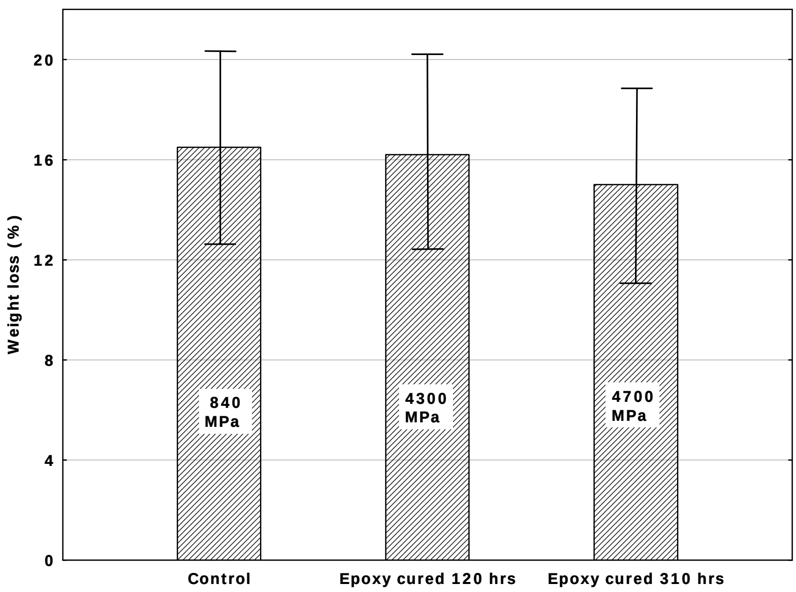

Figure 5.2 Cantabro test results for unoxidised specimens.

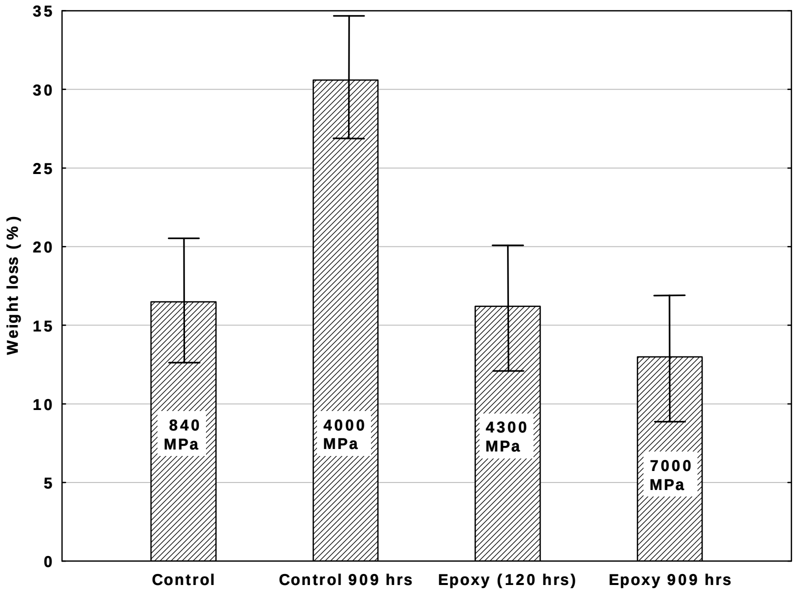

Figure 5.3 Cantabro test results for oxidised specimens.

6. Accelerated loading trial

In addition to the laboratory testing, a limited accelerated loading trial of acid-cured epoxy OGPA was undertaken at the CAPTIF facility. The main purpose of the trial was to provide a demonstration of the technology (epoxy modified asphalt mixtures had not been used previously in New Zealand) and to assess likely practical difficulties associated with full-scale manufacture and construction of the material.

CAPTIF is a 58 m long (along the centreline), unheated indoor circular test track in which full-size pavements are constructed in a 1.5 m deep x 4 m wide concrete trench. Two sets of dual or single tyres with standard heavy vehicle suspension components providing up to 60 kN static load, are driven at up to 50 km/h by hydraulic motors at the end of radial rotor arms, thereby providing realistic dynamic wheel forces (de Pont et al. 2003). A photo of CAPTIF is shown in Figure 6.1.

Figure 6.1 Transit New Zealand's pavement testing facility (CAPTIF).

The asphalt mixtures were manufactured by Fulton Hogan Ltd at their Pound Road plant (about 15 minutes drive from the CAPTIF site). Fulton Hogan also constructed the trial pavements.

6.1 Materials

Local Christchurch greywacke aggregates were used. The control and epoxy mixtures were prepared using the same epoxy bitumen and 80/100 penetration grade bitumen described in Chapter 2.

6.2 Mixture design

The mixture design used for the trial was a standard design used by Fulton Hogan. The design met the TNZ P/11 OGPA specification but differed slightly from that used in the laboratory studies described in Chapter 4. The target bitumen content was 4.8%. The grading of the aggregate used in the two mixtures is shown in Tables 6.1 and 6.2.

Table 6.1 Grading of aggregate in epoxy OGPA.

Sieve size (mm)	13.2	9.5	4.75	2.36	1.18	0.60	0.3	0.15	0.075
Passing (%)	100	93	21	14	10	8	6	4	3

Note: Bitumen content achieved: 4.6% (by pyroloysis oven).

Table 6.2 Grading of aggregate in control OGPA.

Sieve size (mm)	13.2	9.5	4.75	2.36	1.18	0.60	0.3	0.15	0.075
Passing (%)	100	93	17	11	8	6	5	3	2

Note: Bitumen content achieved: 4.9% (by pyroloysis oven).

Compaction of 100 mm diameter specimens for testing was by Marshal Hammer (75 blows per side). Air voids (± 95 % confidence limits) for the epoxy and control specimens were 20.7 ± 0.8 and 21.7 ± 0.4 respectively.

6.3 Manufacture of epoxy OGPA

A turbulent mass continuous mix drum plant was used to manufacture the epoxy OGPA. The major challenge encountered in the process was the correct proportioning of the two epoxy bitumen components into the continuous plant. As the working lifetime of the blended components at high temperatures was too short, simply premixing the two components before introduction to the plant was not feasible without the risk of ‘set-up’ of the material in the tank. An in-line blending system was therefore used instead. Epoxy component B at 120°C was introduced to the drum using a small, standard, heated bitumen tank. Component A was pumped from a 200 L drum, heated to 85°C using heating bands, and entered the line carrying component B about 4 m from the point of discharge into the drum to provide premixing of the two components. The line carrying component A is usually used for the addition of an anti-stripping agent. The pumps used were calibrated to achieve the correct flow rates of the respective components.

As the day of the trial construction was wet and cold (air temperature about 3–4°C) heated aggregate was used to warm the truck decks and prevent the mixture sticking. Release agent was not used on the truck decks as the effect of contamination of the epoxy product was unknown. Dry aggregate was allowed to pass through the drum to ensure the temperature had stabilised at 120°C before manufacture of the asphalts. The epoxy mixture was manufactured first; the first 4–5 tonnes of the control mixture that followed were run through and then discarded to clean the plant. When the manufacture of the asphalt was complete the pumps and lines used to introduce the epoxy bitumen components were drained and flushed with kerosene. Manufacture of the epoxy mixture was found to be straightforward and completed without difficulty. It could be easily undertaken on a larger scale without significant extra cost (except for materials), compared with normal operations.

6.4 Construction of trial pavements

The trial consisted of adjacent control and epoxy OGPA sections each 6 m long, 2 m wide and 30–35 mm thick. The OGPAs were laid on a 200 mm thick pad of dense graded asphalt. An SBS polymer modified bitumen emulsion (about 0.63 L/m^2) tack coat was applied and allowed to break before the asphalt was placed. As the trial was conducted in mid-winter two large (38 kW) diesel-powered heaters were used to raise the temperature of the substrate to about 9–10°C before the asphalts were laid. Construction and compaction by a pedestrian roller, and finally by a tandem steel wheel vibratory roller, required about 15 to 20 minutes for each section. Temperatures during compaction were 80–94°C and 75–80°C for the epoxy and control mixtures respectively. The total time from the commencement of the manufacture of the epoxy mixture to the commencement of construction was 45 to 50 minutes.

No problems in handling or compaction of the epoxy OGPA were noted; its behaviour and appearance was indistinguishable from that of the control material. No unusual fuming or smell was noted. Construction of the trial is shown in Figures 6.2 to 6.6.

Figure 6.2 CAPTIF trial: Polymer modified bitumen emulsion tack coat.

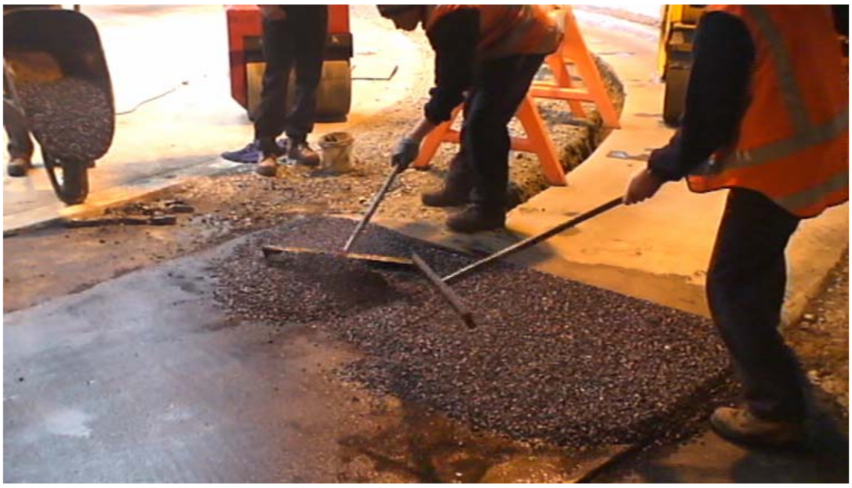

Figure 6.3 CAPTIF trial: Laying epoxy OGPA test section.

Figure 6.4 CAPTIF trial: Initial hand compaction of epoxy test section.

Figure 6.5 CAPTIF trial final compaction of epoxy test section.

Figure 6.6 CAPTIF trial: Test sections after trafficking.

6.5 Curing of epoxy OGPA test sections

Ideally, the behaviour of the epoxy would have been investigated during curing and in the fully cured state to simulate field behaviour. However, owing to limited funding and time constraints associated with the construction and testing programme at CAPTIF, it was not feasible to traffic the epoxy OGPA as it cured. Instead, curing of the epoxy OGPAs was accelerated using heaters over a period of 13 days. The heaters were moved periodically to try and obtain even heating over the entire surface. Using this method, the temperature of the sections was maintained at an average temperature of 29.7°C as shown in Table 6.3.

Table 6.3 Test section temperatures (°C) during curing.

Average	29.7
Median	30.5
Standard deviation	6.8
Minimum	11.7
Maximum	43.0

The rate of cure of the epoxy OGPA was monitored by measuring the modulus of 100 mm diameter cylindrical (Marshall) blocks prepared at the time of construction and placed on the surface of the test sections. The modulus was measured according to the procedure described in Chapter 4 (duplicate blocks were tested). The measured moduli were compared to those of blocks fully cured at 85°C for 120 hours.

After 13 days, the modulus of the epoxy OGPA moduli had increased from 1194 MPa to 2134 MPa, or 57% of the fully cured value of 3909 MPa. Although the fully cured value was comparable to the value of 4300 MPa obtained in the earlier laboratory work (Section 5.1) the initial value was considerably higher, indicating that a greater degree of curing had occurred during manufacture in the plant than in the laboratory. The moduli of the control specimens increased from 928 MPa to 1140 MPa, somewhat higher, though still comparable to the 840 MPa obtained in the earlier laboratory work.

6.6 Cantabro test measurements on CAPTIF trial specimens

The specimens used to determine the extent of curing of the epoxy OGPA test section were cured further at 85°C for 120 hours. Some epoxy and control specimens were then oxidised at 85°C for 909 hours as described in Section 5.2.2. Cantabro testing was conducted at 10°C, which was lower than that used previously but adopted to increase the severity of the test. The results are given in Table 6.4.

Table 6.4 Cantabro test results (% weight lost) at 10°C for CAPTIF trial specimens (± 95% confidence limits).

Mixture	Initial*	After oxidation
Epoxy	14.9 ± 4.6	17.6 ± 4.6
Control	53.1± 5.2	72.1± 7.7

*or after curing 120 hours at 85°C in the case of the epoxy OGPA.

It can be seen from the above table that mass losses for the epoxy OGPA were essentially unaffected by oxidation whereas those of the control increased significantly. The magnitude of the losses for the control was also substantially greater than those obtained earlier when tested at 25°C, but those of the epoxy, both after curing and oxidation, were not significantly different from the 25°C results (about 15%).

These findings indicate that the epoxy bitumen is much less temperature sensitive than conventional bitumen. This confirms the earlier conclusion that the epoxy OGPA should have much improved life in the field compared with mixtures manufactured with standard bitumens.

6.7 Performance of test sections under trafficking

The test sections were trafficked for 198,000 wheel passes over a period of about three weeks. A load of 40 kN was used on each wheel set (equivalent to an 8.2 tonne axle load). After 175,000 passes the tyres were set at an angle of 1.5° from the tangent to increase drag on the surface. The surface temperature during trafficking averaged 12.1°C, as shown in Table 6.5.

Table 6.5 Test section temperatures (°C) during trafficking.

Average	12.1
Median	11.7
Standard deviation	3.6
Minimum	4.2
Maximum	27.7

Performance monitoring included the development of surface rutting and cracking and change in skid resistance and surface texture over time. No response-to-load or deflection testing was conducted as this was not considered relevant to the study.

The epoxy OGPA appeared unaffected by trafficking but the control section, although not extensively damaged, lost a significant amount of chip from the surface at points along the length of the wheelpath.

The development of rutting over time is shown in Figure 6.7. As expected, neither section exhibited excessive rutting after 198,000 passes. Rutting in the control section increased continually with trafficking while the rutting in the epoxy section stabilised after about 60,000 passes, probably reflecting the fact that the OGPA was only partially cured when trafficking commenced. Under field conditions initial trafficking would be applied to essentially uncured asphalt and early rutting might occur. If the modulus of the uncured epoxy OGPA is used as a guide (Section 5.1), then early life rutting is not likely to be more severe than that associated with standard asphalt mixtures. This feature of epoxy bitumen mixtures warrants further investigation.

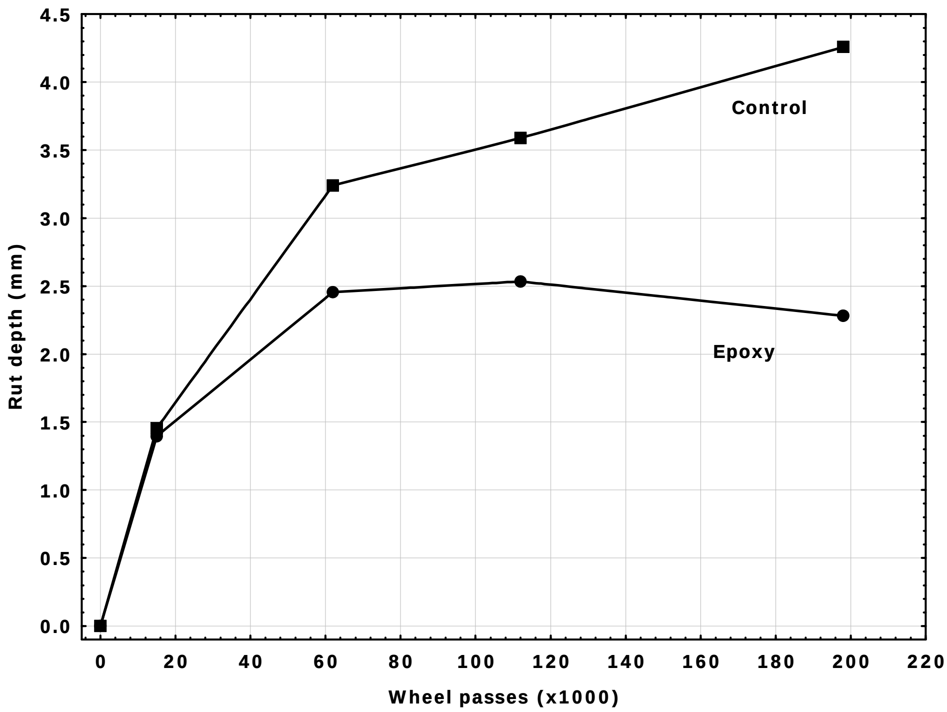

Figure 6.7 CAPTIF trial: Progression of rutting.

Initial skid resistance, measured using the British Pendulum Tester (TNZ Draft T/2) in the wheelpath at three locations, was comparable for both sites (see Table 6.6), demonstrating that the epoxy bitumen was not inherently more slippery than conventional asphalt. After 198,000 passes the skid resistance of the epoxy section, although still acceptable in practice, had decreased slightly, whereas that of the control site had increased beyond its initial value. One explanation for these results is that bitumen had worn from the aggregate surfaces in the control section whereas, in the epoxy OGPA, the binder had instead 'polished' onto the aggregate surfaces in some way, resulting in a reduction in skid resistance. However, the visual appearance of the materials did not appear to be significantly different and a more likely explanation is that the increase in skid resistance of the control section was due to the test results being affected by the surface disruption and abrasion damage observed on its surface.

Table 6.6 Test section skid resistance (British Pendulum Number, replicate measurements).

Section	Initial	After 198,000 passes
Control	65, 64, 64	68, 68, 72
Epoxy	63, 62, 62	56, 59, 58

The observed damage in the control section was not reflected in the texture depth measurements, which were carried out using the sand circle method (TNZ/T3). After 198,000 passes (see Table 6.7) the texture depth in the wheelpath of both sections had decreased equally by about 20% (probably due to blockage of pores in the OGPA by tyre rubber, as rutting was not severe). The sand circle method is, however, relatively insensitive to small amounts of chip loss otherwise obvious to the naked eye.

Table 6.7 Test section texture depth (mm, replicate measurements).

Section	Initial	After 198,000 passes
Control	1.43, 1.50, 1.43	1.18, 1.13, 1.08
Epoxy	1.58, 1.76, 1.67	1.36, 1.36, 1.36

The surface damage observed on the control section was consistent with the Cantabro test results which predicted (at least at 10°C) that the cohesion of the cured epoxy OGPA should be superior to that of the control mixture. The difference in performance was deemed significant given the relatively small number of passes involved and the fact that the epoxy material had not completely cured before trafficking commenced. The Cantabro test results also suggest that the epoxy material should be more resistant to oxidation than the control mixture, ie it should be more durable. A more extensive accelerated loading trial to investigate this possibility was not feasible due to funding constraints.

7. Conclusions

This report has described laboratory investigations into the cohesive properties of OGPA, manufactured using epoxy modified bitumen. The results of an associated accelerated loading test, using Transit New Zealand's CAPTIF facility, to demonstrate the technology are also reported.

The Cantabro test is a severe test of mixture cohesion that relates to the resistance of an OGPA mixture to surface aggregate abrasion losses (fretting or ravelling) in the field. The test results indicated that, for the epoxy bitumen used in this study, the early life cohesive properties of cured epoxy OGPA should be comparable to that of standard OGPA at 25°C and markedly superior at 10°C. The ultimate modulus of the epoxy mixture was much higher than that of the standard OGPA but this is probably of little benefit given that failure through rutting and deformation is uncommon for properly designed OGPA.

As expected, oxidation of the standard OGPA to the equivalent of approximately seven years in the field results in a marked increase (almost double) in mass loss in the Cantabro test carried out at 25°C. In contrast, mass losses from the epoxy OGPA were unaffected by the ageing treatment. The superior oxidation resistance of the epoxy material was even more obvious in Cantabro tests conducted at 10°C. As surface ravelling is the principle failure mode for OGPA these results suggest a markedly improved field life for epoxy bitumen OGPA compared with the standard asphalt.

A limited accelerated pavement testing trial using CAPTIF demonstrated that full-scale manufacture and surfacing construction with epoxy OGPA can be easily undertaken without any significant modification to plant, machinery or operating procedures. Limited trafficking of the test sections (198,000 wheel passes including a skewed tyre to increase drag late in the trial) resulted in early signs of surface abrasion in the control section but not in the epoxy, behaviour consistent with that predicted from the Cantabro test results. Early life rutting of epoxy mixtures is not likely to be greater than that of equivalent standard materials but should not detract from their apparent advantages. Further investigation of early life behaviour in the field is warranted.

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