Maximising Stabilisation and Recycling Benefits for Sustainable Pavement Performance in New Zealand & Australia

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Abstract The stabilisation of granular pavement materials and/or underlying soils is accepted practice in Australasia (i.e. Australia and New Zealand). Stabilisation in this context involves the mechanical introduction of reactive agents, typically lime, cement and foamed bitumen. The reuse/recycling of aged existing pavement materials is imperative for sustainable management of finite resources. Reduction in aggregate availability has hastened the need for development of insitu stabilisation to rehabilitate the pavement alongside other performance gains. Hiway Group have commissioned laboratory research and undertaken extensive field trials in partnership with industry and academic partners to lead industry adoption and confidence in sustainable recycling. This paper will outline a variety of proven approaches ranging from hot in-place asphalt recycling through aggregate stabilisation treatments employing waste materials such as ground steel slag to innovative processes to mitigate and control deleterious subgrade soils and low ground pressure fill drying methodologies. Case studies such as exhuming 30+ year-old pavements to evaluate durability of lime stabilised layers will be outlined through to recent research and field trials that successfully incorporate substantial proportions of waste plastic, glass, steel slag and concrete blended recycled aggregates. Examples of structural benefits will be detailed that have been monitored to substantiate performance and calibrate design parameters.

Keywords: Sustainable Pavement Recycling Stabilisation

1 Introduction

Hiway Stabilizers NZ (now Hiway Group) commenced in 1986 with a mission statement to integrate insitu stabilisation and recycling to civil works (especially roading) and since then has worked throughout the Pacific, established a strong presence in Australia and grown to be Australasia's largest stabilisation / insitu recycling contractor. Hiways' have maintained a close relationship with research and academic entities through this time to provide robust and independent support for a myriad of innovative recycling initiatives over the last three decades.

Extraction of roading aggregate can only occur where the resource can be economically processed and transported to local markets. An additional 30 km travel distance typically doubles the cost of aggregate. Reprocessing recycled materials can consume substantially fewer resources than extracting and processing raw materials. The purpose of this paper is to outline commonly accepted best practice utilizing stabilisation in New Zealand / Australia, discuss some options to increase recycling and outline innovations that have been accepted and implemented by wider industry.

2 Industry Groups as a Conduit to Encourage Recycling

The NZ National Pavements Technical Group contains 14 pavement/materials specialists representing contracting, consulting, local authority, and national highway roading authorities. This group provides a formal value gateway role for the NZ Transport Agency by providing industry feedback on best practice, specification initiatives, innovation and research prioritization. Significant industry accomplishments include the development of stabilisation specifications, industry best practice notes, and most importantly a trusted platform for roading authorities to obtain industry feedback prior to a more general release.

Australia does not have a similar cross-industry focus group, and this is perhaps understandable with six states each having its own state road authority and different regional materials, design and construction protocols. An industry group AustStab (established in 1995), strive to raise the awareness of stabilisation in the industry, particularly recycling of pavements, formulation of specifications, technical notes and training courses covering all elements of stabilisation best practice.

3 Practices and Experience

3.1 Historic Subgrade Lime Stabilisation in New Zealand

Lime stabilisation was used sparingly in NZ before 1978, at which point a trial project was tendered for subgrade stabilisation on an Auckland Road upgrade. This project had the benefit of intensive post construction evaluation through 1979 to the late 1990's. The same section of road was re-tested in 2009 and a sequence of insitu and laboratory testing was undertaken to provide ongoing 'in-service' stabilised subgrade parameters. The original design life was 15-years, but 40 years later the stabilised subgrade is still performing exceptionally. The natural subgrade strength was soaked and remoulded subgrade CBR = 4, while the design strength of the subgrade stabilised with 4% lime (Calcium Hydroxide) was CBR = 25.

Annual performance evaluation through 1979 to 1983 revealed insitu CBR strength of CBR 100+. Further research testing (Transfund Research Report No. 127) in 1998 reported that “the strength and modulus properties of the stabilised subgrade are significantly superior to those of the original subgrade and this benefit has persisted for more than 20 years”. Subsequent investigation in 2009 showed insitu CBR of 90+.

This 2009 research showed that despite the recognised process control limitations and stabilisation methodology of 1978 (i.e. variable layer thickness and intra-layer laminations), the layer properties and durability are excellent. The quality of spreading, stabilising and compaction plant has advanced tremendously over recent years and the level of assurance in obtaining dependable design parameters is very high relative to what was possible in the 1970’s and 1980’s.

A requirement raised by industry around soils stabilisation is expectation of permanence. Most importantly these improved material properties have been maintained for a sustained period of years with no relaxation thus confirming the durability of lime stabilised soils permanence of the pozzolanic reaction once lime demand and good mixing is ensured. One of the most significant opportunities for aggregate savings in pavements is the incorporation of a stabilised subgrade. NZ and Australia have seen industry advances such as a new Lime (hydrated or quicklime) subgrade stabilisation mix design and structural design specifications with significant improvement in construction protocols and quality assurance.

3.2 Subgrade Lime Stabilisation in Australia

Australian subgrade stabilisation employs several different design philosophies. The consistent initial methodology is to test for the lime ‘demand’ (i.e. quantity of lime required to attain the pH of 12.4) for ensuring a full and permanent pozzolanic reaction. This has led to a high level of success of the insitu lime stabilisation process but can require relatively large application rates. Some soils such as the highly expansive black cotton soils can require more than 6% application rate for lime demand.

In recent years two design protocols have been formalized in Austroads Part 4D (V2.1 April 2019). Method A requires lime application to achieve a laboratory 28-day Unconfined Compressive Strength of 1.0 to 2.0MPa, while Method B requires the 7-day soaked CBR of the material to be tested and a design CBR derived of no more than half the laboratory mix design value. Both methods constrain the subgrade to a maximum strength of CBR = 15 / Resilient Modulus = 150MPa, and also limit the design top sublayer modulus to a Modular Ratio dependent on the support provided by the underlying ‘unstabilised’ material determined using AGPT Part 2 Equation 39 as follows in Eq (1) below:

$$E_{V\,\text{top sublayer}} = E_{V\,\text{underlying material}} \times 2^{(\text{thickness of each selected subgrade or stabilised subgrade layer}/150)} \quad (1)$$

Method A typically requires greater quantities of lime and is mainly used by Queensland DTMR. Method B is more commonly used by other local government or State Road Authorities. Some designers require a greater factor of safety, such as in Victoria where a reduction factor of 3 (i.e. Design CBR = 1/3 x Laboratory CBR) is typically required. Economic viability of subgrade stabilisation can thus be significantly influenced by geographic location and design protocol.

3.3 Employment of Subgrade Lime Stabilisation in New Zealand

Major projects incorporating lime stabilised subgrades have been an accepted part of New Zealand major project philosophy for new pavement construction for several decades in the North Island. The predominant soil types (Waitemata Group clayey silts and Northland Allochthon silty clays) have a naturally alkaline pH of 8.0 to 9.5 meaning only small quantities (1 to 2%) of lime are required to achieve pH of 12.4. While lime demand testing is recommended it is not regularly undertaken. New Zealand design protocols are to determine dependable soaked CBR strength with capacity reduction factor. This capacity reduction factor is typically 2 for laboratory to field (i.e. CBR of 20 in the laboratory allows a design subgrade CBR = 10) with a maximum permissible design subgrade of CBR = 15 as per the Austroads design guide.

A well-constructed stabilised subgrade will provide a strong and durable substrate that can replace a depth of aggregate virtually equivalent to the stabilised layer thickness. This also provides an improved construction anvil that is highly resistant to effects of moisture, preventing “aggregate punch” and upward migration of plastic fines into the overlying aggregate. A well designed stabilised subgrade can also deliver a ‘perpetual’ lower pavement system that can accommodate future rehabilitation at the end of the effective life of the upper aggregate courses.

3.4 Fill Drying

An extension of lime subgrade stabilisation is the use of low ground pressure (tracked) equipment to modify / strengthen weak soil layers to where they can be utilized rather than cut to waste. Industry has developed purpose-built equipment for spreading and stabilisation and this has seen the development of a variety of blends of lime and cement to optimize the strength and minimise moisture sensitivity.

Fill drying work, while traditionally used for roading infrastructure, has found high demand in the treatment of residential housing and commercial developments to heavy duty hardstands etc. Employing fill drying stabilisation provides many platform benefits beyond drying and strength gain with a stable platform reducing soil particle migration into overlying aggregates, reduced plasticity / moisture sensitivity, and most importantly less demand on finite virgin aggregate resources.

Fig. 1 Example of Low Ground Pressure Spreader and Stabilizer Undertaking Fill Drying

Fill drying can significantly decrease construction time where the conventional methods are cut-to-fill (or waste) or 'discing' to expose wet soils for air drying. Air drying is frequently compromised by rainfall. Lime fill drying will generate quicker drying from heat generated by hydration of quicklime (calcium oxide). A fill drying technique commonly used is to spread and mix unslaked quicklime (3mm topsize) fines where moisture is consumed from hydration and heat. Refer to Eq (2).

Quicklime CaO + water H20 ➡ Calcium Hydroxide Ca(OH)2 + HEAT (2)

The speed of curing and soil stiffness gain is enhanced by the heat of hydration with the added advantage of excess moisture consumption to dry the soils and aid in achieving optimum density. This process has been carried out for millions of cubic metres through the last two decades in New Zealand, and in recent years has been introduced to Victoria and NSW in Australia. The benefit to natural resources is the enormous reductions in virgin aggregate consumption, and the associated reduction in damage to the roading network otherwise caused by haulage of aggregates and building materials to the construction site.

4 Hot In-Place Asphalt Recycling (HIPAR)

HIPAR comprises reheating and gentle hot-milling of asphalt surfacing with the addition of a rejuvenating agent during inline pugmill remixing, then the recycled mix is paver laid in a single continuous process. Robust pavement structure is required where failure is within the aged oxidized, cracked or ravelled asphalt surfacing. The insitu remediation can be modified with a small quantity of 'make-up' asphalt to ensure the depth and geometric shape meet the needs of the traffic and asset lifecycle.

HIPAR was first utilized for the Queensland Department of Main Roads in 1990 and many of these sites are still monitored. The equipment is expensive and currently there is only one HIPAR resource in Australasia. Direct savings are typically 15 to 20% when compared to a conventional mill and resurface option and there are other environmental benefits such as zero waste leaving the site, reduced truck movements / damage to adjacent road networks, speed of operation reducing traffic disruption, strong bond with underlying asphalt due to heated contact. The stability of the 42-tonne remixer / paver provides for enhanced smoothness and ride properties.

The design process assesses the asphalt to be recycled and the suitability of the existing bitumen via Viscosity tests (Test Method QTMR Test Method No. Q337 previously, but now AS2341.5) which measure binder viscosity using slide plates. Australian practice has determined the onset of cracking due to bitumen hardening (ageing) is where bitumen achieves a critical viscosity of $7x10^6$ Pas (6.86 log Pas). For fresh Class 320 bitumen the apparent viscosity is expected to be 4.3 log Pas, and any value exceeding this value will indicate the need for chemical analyses to establish what recycling agent is required to restore the properties of the aged binder.

Fig. 2a HIPAR Schematic Illustration

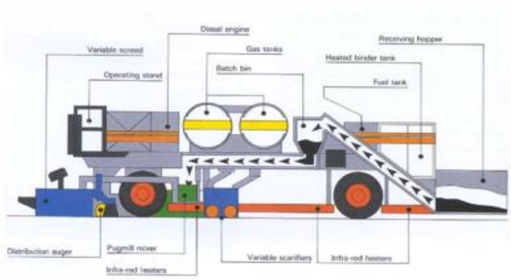
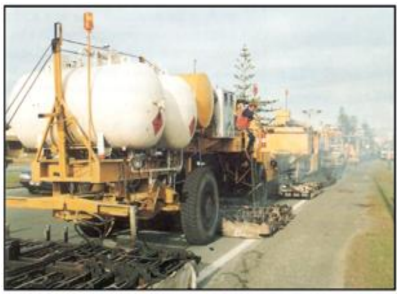


Fig. 2b Gas Heaters Operating in Front of HIPAR



The bitumen rejuvenator is Rejuvenex 60E oil applied at ~ 0.7litres/m2 for 50mm treatment depth. Recent research simulates the HIPAR 125degC heating, milling, 30-second pugmill mixing time then screw-fed paving. The Marshall specimens are prepared immediately (i.e. without any curing time). The specimens are tested to simulate early strength and are also placed in an 85degC oven for accelerated curing of up to 40 days to simulate aging for testing of long-term fatigue properties.

Challenges for more widespread adoption include high cost of plant, specialized training for operators, selecting sites with failure mode comprising aged/oxidized wearing course (not structural). The recent prevalence of polymers is another consideration regarding management of fumes from heating modified binder asphalts.

Industry has been undertaking research using Epoxy in the place of rejuvenator to assess strength and fatigue capacity for HIPAR. This has been successful for open graded porous asphalts, but dense graded asphalts are more challenging with the quantity of epoxy required for full binder film coverage compromising volumetrics. Compounding this is the difficulty in achieving effective mixing of the epoxy with the hardened bitumen films in the recycled asphalt with the small amount of mixing time available. On this basis dense asphalt recycling with epoxy requires gradation adjustment and as such is better suited to exsitu / plant-based process where more mixing time and better feedstock control is possible.

5 Steel Slag Byproduct as Stabilizing Agent for Roading

During the 1990's NZ Industry pioneered the use of ground waste slag for use as a stabilisation binder. KOBM (Kontinuous Oxygen Blast Maxiite) is a by-product from the steel making process where Lime is added to the smelt to remove impurities from the steel products. The composition of ready-to-use KOBM binder (ground to a 3mm topsize) is 45 to 50% Calcium Oxide, 13-15% Iron total, 8% Magnesium Oxide 6% Silicon Dioxide and then several other trace minerals.

The reaction occurs between the hydrated Calcium Oxide in the slag and the clay minerals in the roading aggregates. This plasticity reduction with only minor strength gain means that KOBM is typically used as a pretreatment binder for high plasticity aggregates prior to foamed bitumen stabilisation (employed since 2007) or used in a blended product with conventional binders such as cement (since 1997).

Fig. 3: Steel Serve Glenbrook KOBM Analytical Report and Particle Size Distribution Summary

Client ID	Fe Total	CaO	SiO_2	TiO_2	Al_2O_3	MgO	P_2O_5	Na_2O	K_2O	S	V_2O_3	MnO
	%	%	%	%	%	%	%	%	%	%	%	%
KOBM 3mm 159/18	13.69	48.9	<6.83	2.76	1.74	8.03	1.4	<0.010	<0.010	0.13	3.26	2.36

Sieve Size (mm)	9.5	6.7	4.75	2.36	1.18	0.6	0.3	0.15	0.075			
% Passing 159/18	100	100	100	87	67	57	49	37	21			

The recycling benefit of KOBM is in taking a processed by-product / waste material and utilizing it to modify poor quality aggregates to mitigate plasticity and improve shear strength / resilient modulus. Another advantage is that the KOBM is only a fraction of the cost of burnt lime and cement. KOBM is typically specified at 2% to 4% application rate (by mass) depending on the process and material properties.

NZ KOBM use follows extensive early independent research in the 1990's then ongoing field trials and monitored pavement rehabilitations. The high specific gravity of KOBM (relative to lime or cement) means increased cartage cost, but conversely provides a more stable product than lime as it is less susceptible to wind movement, so is the preferred pre-treatment product for urban or environmentally sensitive locations. Leachate testing suggests that constituents are not mobilized where KOBM is used with foamed bitumen or cement stabilisation. This is especially noted in foamed bitumen where permeability reduces by an order of magnitude and the fines are immobilized. Note, research also demonstrates that foamed bitumen is also employed for Coal Tar mitigation via immobilization ad reduced permeability.

KOBM is an alkaline material and therefore is handled with some caution. The high pH expedites the pozzolanic reaction for the liberated Calcium Oxide with the aluminates and silicates present in the clay fines. The KOBM is stored under cover as when exposed the Calcium Oxide carbonates to form Calcium Carbonate over time – losing reactivity. The melter slag available from Australian steel mills is of a different composition to New Zealand, and currently high Calcium Oxide slag by-product is not available in commercial quantities.

6 Foamed Bitumen Incorporating Recycled Materials

Foamed bitumen 'cold' insitu recycling was undertaken in Australasia through the 80's and 90's but gained substantial traction with the evolution of purpose-built stabilisation equipment since the early 00's. Foamed bitumen is seen as a cheaper alternative to structural asphalt or concrete for highly loaded expressways and arterials. Insitu treatment is also popular for level constrained urban rehabilitations.

Foamed bitumen in Australia gained additional support in recent years with the demonstration of resilience following the extensive Queensland flooding events of 2010/11 then 2013. Current research by Austroads and the Australian Road Research Board (ARRB) produced several encouraging performance metrics with test tracks constructed. A foamed bitumen stabilised materials test pavement consisting of three fatigue trial sections was constructed including a control section made with a class 3 20 mm crushed rock (granite), a section containing 80% previously cement treated material and section containing 50% RAP. All the test sections were stabilised with 3% foamed bitumen and 2% hydrated lime. These were designed to fail but performance was better than anticipated and the conclusion was that all foamed bitumen stabilised material iterations have performance better than expected. This initial evidence does suggest foamed bitumen stabilisation to be an excellent treatment for pavement rehabilitation, whether that be incorporating a pure host material, RAP or previously cement treated material. This is encouraging for confidence in utilizing more recycled material constituents for foamed bitumen treatment as opposed to cutting existing materials to waste and importing virgin aggregates.

Preference in some states for exsitu plant mixed foamed bitumen shows regional preference of associated active filler, with lime preferred in Queensland, NSW, Northern Territories and cement in Victoria, South Australia and Western Australia. The key is to ensure that active filler content is limited such that the bitumen contribution is dominant, and the desired ductile performance of the treated aggregate is maintained such that it does not become rigid / brittle and risk to crack failure.

Insitu foamed bitumen stabilisation permits full recycling of existing basecourse aggregates. In some materials plasticity mitigation is required before treatment, and in others mechanical stabilisation is required via supplementary fine or coarse aggregate fractions to optimize the particle size grading before foamed bitumen treatment.

Further to recycling existing aged aggregates, the preparation of high waste stream mix designs with aggregates comprising recycled crushed concrete and/or recycled asphalt has provided strong results and subsequent project utilisation. Furthermore, other laboratory and trial pavements have incorporated up to 35% recycled crushed glass where performance was exceptional, although the high proportion of crushed glass was prone to raveling when trafficked heavily before surfacing.

7 Dry Matting Recycling of Flushed Chip-Seal Surfacing Binder

HiTex dry matting is an alternative surface treatment for heavily flushed sprayed seal roads. Excess bitumen used to be burnt/set alight but this is no longer environmentally acceptable, so current approaches are to 1) 'watercut' (where there is a high risk of damaging seal coat with water-blaster overcutting), 2) profile surfacing to waste or 3) recycle surfacing into underlying basecourse via stabilisation.

The HiTex dry matting process utilizes the mobile HIPAR gas heater bank(s) in conjunction with sealing chip for volumetric improvement. The treatment methodology consists of spreading a light coating of 10mm or (more typically) 14mm sealing chip on the road to allow heater banks to pass over the heated flushed pavement. The ground speed is managed to optimize fluidity of the bitumen (Targeting 145 to 150degC) to receive the additional sealing chip immediately behind the heater banks. The flushed portions of the pavement present liquefied bitumen while the non-flushed areas have lesser temperature due to the chip cover so the introduced chip bonds to the flushed portions and the chip placement/rolling "beds in" the introduced chip where required to correct wearing course volumetrics. Some additional chip may be hand spread for any localized more heavily flushed areas. Following compaction, the surplus chip is swept away , or where possible, it is reclaimed.

HiTex has been adapted for single lane treatment with smaller 0.6 to 1.0m heater banks to permit focused treatment of pavements where wheeltrack flushing requires remediation. The large-scale heater banks can extend to 4.2m width at full extension.

This treatment has been successfully undertaken for full pavement flushing through to more channelised wheeltrack flushing and can be employed as part of a poor texture mitigation process prior to full resurfacing, or as a holding maintenance treatment to extend timing until resurfacing is required. Some management of variable texture is required, and close attention to bitumen temperature is also required. The process is self-correcting with the introduced chip requiring liquefied bitumen (from the flushed portions of the pavement surface) to bond to otherwise it is removed.

8 Conclusions

There is widespread desire to incorporate recycling for sustainable pavements in Australasia for different applications as outlined in this paper. There are, however, many barriers to wider utilisation including lack of cross-industry consistency around recycling design protocols and specifications as well as limited desire of stakeholders to incorporate alternatives and/or manage perceived risk around recycling. Recycling, while usually providing cost savings, will inevitably involve different and typically higher risks and these need to be understood and categorized / managed rather than attempting to eliminate all risk.

Initiatives to encourage recycling practices include development of robust cross-industry recycling design guidelines and construction specifications, contract documents that incorporate minimum recycling project requirements or projects that contain incentives or attributes recognizing the use of recycling in tender evaluation.

Independent industry research and post construction evaluation is required to 'calibrate' the long-term performance of modified / recycled materials against laboratory mix design and construction quality assurance test data to provide confidence in dependable field performance. Validated performance criteria for innovative and non-conventional materials and processes substantially increase the desire for utilisation as an alternative, or ultimately being considered a part of conventional practice.

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