

POLYMER STABILISATION OF CLAYEY GRAVELS

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ABSTRACT

Recycling of roads by stabilising with cement, and more recently with other slower-setting cementitious additives, is a well-documented process. An alternative additive, an Australian-developed 'Dry Powdered Polymer', has been increasingly used in recent years. It is particularly applicable in situations where it is not possible to achieve a depth of cemented layer sufficient to produce an adequate fatigue life. In a number of instances, cementitiously-stabilised pavements of inadequate depth have suffered serious cracking and pumping within one to five years of construction, and expensive recycling has been necessary.

Dry Powdered Polymers are especially suited for treating poorer quality, clayey gravels that lose considerable strength if they wet up in service. They have particular application in regions of high water table and where periodic flooding of shoulders occurs. They preserve the gravel's dry strength in two ways. Firstly they reduce the amount by which the gravel wets up in service. Secondly they reduce the softening effect of any water that does enter the gravel. These two mechanisms are referred to as 'external' and 'internal' waterproofing. The polymer-treated gravel remains flexible and is not subject to either shrinkage cracking or load-induced fatigue cracking.

In Australia, pavements are now usually designed using mechanistic methods detailed in the Austroads Structural Design Guide. Because the design methods focus on pavement stiffness (elastic modulus) they cannot directly take into account the main improvements produced by the polymer. These are reduced plastic deformation of the drier stabilised layer, an absence of shrinkage and fatigue cracking, and a water barrier over the subgrade. Consequently the mechanistic methods are not well suited to designing polymer-stabilised pavements. Designers must currently largely rely on the accumulating field evidence to assess the effectiveness of the polymer, so continuing efforts to document the performance of treated pavements are required.

Key Words: pavements, stabilisation, recycling, polymer.

INTRODUCTION

In recent years, stabilising machines capable of efficient and thorough insitu remixing of existing pavements to depths of 400mm have become available in Australia. This has opened the way to economically improve roads to cater for heavy traffic. Many have been successfully recycled, commonly using cementitious additives.

When unbound gravels are strengthened by cementing the particles together to produce significant tensile strength, unavoidable shrinkage accompanies the cementing process and causes some cracking of the newly strengthened pavement. Sealing of the cracks is then usually necessary otherwise pumping of fines can lead to premature failure. In most cases in practice the potential problems arising from shrinkage can be effectively managed. Where slower-setting cementitious additives are used, cracking of the treated layer often consists of only fine cracks.

The potential for fatigue cracking that accompanies the new rigidity of the strengthened layer is of greater concern than shrinkage cracks. The fatigue performance of the bound pavement is sensitive to vehicle overloads and to localised deficiencies in thickness or stiffness of the treated layer. In some situations it may not be feasible to construct cementitiously-stabilised basecourses of sufficient thickness to prevent fatigue cracking for the required design life. This may be due to limited funding or to limited depths of existing pavement suitable for insitu stabilisation. Treatment depths of 150mm to 250mm are common. Also, practical limits to the amount of site investigation that can be done often means that the variation in both the quality and depth of the insitu pavement gravel along the road is not well defined. Because of this, some plastic subgrade might be incorporated into the stabilised layer. The design stiffnesses are not then consistently achieved. In these circumstances, stabilisation with Dry Powdered Polymer may be an attractive alternative, because it is not prone to fatigue cracking and its performance is less sensitive to vehicle overloads and to deficiencies in thickness of the treated gravel. Also, because the treated layer remains flexible, no special surfacings are needed to combat reflection cracking. Thus the additional expense of stress absorbing membrane interlayers (SAMIs), rubberised seals, geofabrics, modified binder asphalts, thick asphalt overlays or granular overlays may be avoided. These savings should be taken into account when comparing the polymer with cementitious alternatives.

All insitu stabilisation methods provide considerable savings compared with new construction, but it is difficult to be specific because cost relativities are so project-dependant. However, cementitious treatments and polymer treatments are often comparable in cost and are both less expensive than bitumen stabilisation. Initial costs are affected by factors such as location, different stabilisation depths required for each additive, and the designer's judgement on the need for special surfacings to combat reflection cracking if applicable.

In Australia, pavements are now usually designed using the mechanistic pavement design procedures detailed in the Austroads Guide to the Structural Design of Road Pavements (Austroads, 1992). Surface rutting is controlled by limiting the vertical compressive strain at the top of the subgrade. The strain is calculated using the layered elastic computer program, CIRCLY (Wardle, 1999). Increases in calculated pavement rutting life only occur if the stabilisation process increases layer stiffness. Consequently the CIRCLY-calculated estimates of pavement life are conservative for additives that also improve pavements in ways other than by increasing stiffness. Specifically, the design method cannot factor in the benefits of reduced plastic deformation of the stabilised layer itself, the absence of shrinkage and fatigue cracking, and also the benefits of a water barrier over the subgrade. A higher design CBR for the subgrade would be warranted where the subgrade remains drier in service due to the lower permeability of the polymer-treated basecourse. The conservatism inherent in the mechanistic design method acts as an impediment to the use of waterproofing additives if designers attempt to evaluate them by CIRCLY analyses alone. Designers must currently largely rely on the accumulating field evidence to assess the effectiveness of polymer treatments. Consequently continuing efforts to document the performance of these pavements are required.

CEMENTITIOUS STABILISATION

The processes and criteria for use of cementitious stabilisation are well covered in the technical literature including (Wilmot, 1994) and the Austroads Guide to Stabilisation in Roadworks (Austroads, 1998).

The high stiffnesses readily produced by cementitious stabilisation mean that, theoretically, the need to protect the subgrade against rutting is met by very small depths of stabilisation. However, much greater depths are needed to protect the stabilised layer itself against fatigue cracking. That is, the design is governed by the fatigue criterion for the cemented layer, not by the subgrade rutting criterion. For example, consider an existing 250mm thick unbound gravel pavement over CBR 5 subgrade and design traffic of 100,000 ESAs. CIRCLY calculations indicate that stabilisation to a depth of only 55mm is required to protect the subgrade against rutting failure, assuming that a stiffness of 3500 MPa is achieved in the stabilised layer. But to prevent fatigue cracking under 100,000 strain repetitions, a stabilised layer of 290mm, not 55mm, is needed. In this case the stabilisation depth is limited to 250mm by the thickness of the existing pavement, which CIRCLY indicates would have a fatigue life of 7,000 ESAs, only 7% of that required. This high sensitivity to achieved thickness has been noted earlier in this paper. However, in practice 200mm thick gravels, moderately bound to achieve moduli of around 1000 MPa, have often performed considerably

better than predicted by the current Austroads fatigue criteria for cemented materials. This suggests that they are functioning as improved, or 'modified' unbound materials rather than as truly cemented materials.

Considerable lengths of cementitiously-stabilised pavements have failed within 1 to 5 years due mainly to inadequate design thickness. Failure usually entails fatigue cracking of the stabilised layer, leading to pumping of subgrade, further cracking of undermined sections, and ultimately faulting of the pavement across cracks. Rehabilitation by overlay is not usually appropriate because the cracks quickly reflect through the overlay. Recycling of the cracked pavements can be expensive, however, due to the high strengths that are sometimes developed over time by the stabilised layer. Typically, 150mm diameter cores are taken and tested in compression to assess the cost and difficulty of recycling, and to assist in the selection of recycling equipment. The cost of recycling a 200mm thick layer using a pavement recycler such as the RS 500 is about \$4 per square metre. This can double, however, if core strengths of around 8MPa are encountered over significant lengths of the stabilised pavement. For higher strengths, excavation using a profiler rather than a recycler may be needed but costs of around \$10 per square metre could then be expected. Core strengths of up to 18 MPa have been measured in parts of some stabilised pavements. The excavated material is typically re-used as an unbound subbase and overlaid with an imported granular basecourse. However it may be re-stabilised and function as a basecourse to an asphalt or sprayed seal surfacing layer.

In summary, there are many situations in practice where adequate design pavement depth cannot be afforded, or cannot be consistently achieved during construction. In these situations, especially where vehicle overloading is expected, stabilisation methods that produce a flexible, unbound layer have advantages over those that produce a bound layer. The pavements can be readily upgraded by overlay when required, using the initial stabilised layer as subbase; expensive recycling is then avoided.

DRY POWDERED POLYMER STABILISATION

The new Austroads Stabilisation Guide deals only briefly with polymers (Sections 8.3.1, Polymer in Dry Powder Form, and 9.8.2.3, Powdered Polymer Stabilisers) so the material and the stabilisation process are described here in some detail. The Australian Stabilisation Industry Association (AustStab) has proposed that the material be defined as 'A dry powdered road stabilisation additive (binder) consisting of an insoluble polymer thermally bound to a very fine carrier such as flyash'. This comprehensive definition was deemed necessary to avoid confusion with water-soluble liquid stabilisers that are sometimes referred to as polymers. The stabilising powder consists of a coating of polymer thermally bound to a fine carrier, typically flyash, which is then mixed with hydrated lime. The lime is not coated with polymer. Its function is to flocculate clay particles within the gravel and prepare them for adhesion to the polymer. The flyash is encapsulated by the polymer and so is effectively inert and does not react chemically in the stabilisation process. Its function is that of a carrier to facilitate the distribution of the polymer throughout the gravel. Therefore it is misleading to compare the product with stabilising agents that contain flyash/lime mixtures. The latter act quite differently and involve pozzolanic reactions that produce cementitious bonds.

Two products are commercially available, Polyroad PR21L and PR11L. The first consists of a mixture of two parts polymer-coated flyash and one part hydrated lime. The second differs only in that it contains one part polymer-coated flyash and one part hydrated lime. It is used for higher plasticity gravels that need more lime to flocculate the clays. PR21L is normally used for gravels with a Plasticity Index up to 12. The dosage rates for the products are 1.5% and 2% respectively of the dry mass of treated gravel. Thus in either case 1% of polymer-coated flyash is used. For gravels, based on the capillary tests described below, 1% is ample to produce the desired waterproofing effects. Because this dosage rate is low relative to many other stabilisation additives it is important to dose accurately and mix thoroughly.

How Polymer 'works'

Many road gravels have adequate strength to resist traffic stresses when they are dry but dramatically lose this strength with the increases in moisture contents that often occur in service. When wet, the clay fines within the gravel become 'greasy' and lubricate the larger stones. This allows them to slide relative to each other to produce rutting when subjected to wheel loads. Strength loss can be particularly pronounced for gravels that have smooth, rounded coarse stones and highly plastic fines.

Polymers act to preserve the 'adequate' dry strength of water-susceptible gravels by a dual process of 'external' and 'internal' waterproofing. This involves creating a hydrophobic soil matrix between the larger stones, which reduces permeability and so limits water ingress ('external' waterproofing). Also, because the polymer is so strongly attracted to clay particles, it displaces water from the clay. Thus the softening and lubricating effect of any moisture that does enter the pavement is much reduced ('internal' waterproofing).

A simple laboratory test is used to quickly confirm, for any gravel proposed for treatment, that the polymer does in fact produce the intended external waterproofing effect. Compacted 100mm high cylindrical samples of both untreated and treated gravel are allowed to dry back for a few days then placed in a tray containing 30mm of water. After 24 hours the capillary moisture is typically seen to rise to near the top of the untreated sample and the sample begins to disintegrate below the 30mm waterline. By contrast, the polymer-treated sample typically suffers only a moderate capillary rise of around 25mm and the sample remains intact below the waterline. The effectiveness of the waterproofing treatment is further demonstrated by squirting drops of water onto the dry top of each sample. The water immediately soaks into the untreated sample but forms beads on the treated sample. Materials suitable for treatment contain fines sufficient to form a matrix between large aggregate particles, and also exhibit some plasticity. Little or no improvement would be expected, for example, in the case of a non-plastic crushed rock, or where the grading is such that large, interconnected air voids remain after compaction.

The Polymer's 'internal' waterproofing effect is best confirmed by triaxial testing of the kind that was done for a Taree Aerodrome project described below.

Taree Runway 1988 trial of Dry Powdered Polymer.

Pavement failures at Taree aerodrome were investigated in 1988. The runway pavement was performing well during dry weather but, after rain, localised rutting quickly occurred under Fokker Friendship aircraft loadings (dual wheel loads of 8 tonnes), and frequent patching was necessary.

The pavement consisted of an aged, permeable, sprayed seal over a basecourse of conglomerate gravel that was composed of smooth rounded coarse stones within a moderately plastic (Plasticity Index 9) matrix. This suggested that the basecourse might be relatively strong when dry but that it would lose considerable strength when wet. This was confirmed and quantified by laboratory testing. Parallel samples were prepared for Californian Bearing Ratio testing. Samples were compacted to identical densities at the optimum moisture content of 6% and also at 7.5%, 1.5% wet of optimum. This small increase in moisture content reduced the CBR from 60% to 35%. Excavation of failed sections revealed that the rutting was confined to the basecourse gravel. The subgrade was undeformed.

Cement stabilisation had been tried previously in another section of the runway. The client's concern that cement stabilisation would again produce cracking problems prompted a trial of dry powdered polymer on a 50 metre, full width section of the runway.

In addition to CBR testing, triaxial tests were conducted to investigate the claimed effectiveness of polymer in reducing the strength loss caused by moisture increase in clayey gravels (called 'internal waterproofing'). The results are given in Table 1. As was expected, the untreated plastic gravel had high shear strength when tested very dry of optimum and the strength reduced dramatically when tested 2% wet of optimum. Compared to the untreated material, the polymer-stabilised sample retained relatively high shear strength even when tested 3% wet of optimum.

The top 150mm of conglomerate gravel basecourse was polymer-stabilised insitu in September 1988 and resealed. It continues to perform well after twelve years. While the polymer molecular structure is essentially stable, and so breakdown of the waterproofing effect of the polymer is not expected to occur in service, the Taree trial is valuable in that it provides the best field evidence to date of the permanence of polymer-stabilisation.

Table 1. Triaxial tests on treated and untreated Taree gravel.

Test Specimen	Moisture Content (%)	Cohesion (KPa)	Friction Angle (Degrees)	Dry Density (tonnes/m³)
Dry untreated gravel	1.6	450	39	2.18
Wet untreated gravel	8.2	0	22	2.11
Wet polymer-treated gravel	8.9	125	37	2.02

The Taree experience is especially relevant to Local Government roadworks where local basecourse gravels that are marginal with respect to plasticity, grading and soundness must often be used. In these situations, marginal basecourses, rather than the subgrade, can be the primary source of pavement failure. In such cases, the Austroads mechanistic rutting design procedure based on subgrade deformation would be a poor predictor of pavement performance.

Australian usage of dry powdered polymer

Polymer stabilisation has now been used by NSW, Victorian, Queensland and Tasmanian State Road Authorities and also by Local Government Authorities including Yass, Singleton, Wagga, Gosford, Urana, Warnambool, Phillip Island and Thuringa. Stabilisation depths of 150 to 200mm are most common but depths up to 350mm have been used. Overseas locations include Port Moresby, the UK and Brunei. The approximate usage within Australia for the past ten years is indicated in table 2. Tonnages are given in lane kilometres based on the typical treatment depth of 200mm and a typical dosage rate of 1.5% PR21L (1% polymer-coated flyash and 0.5% hydrated lime).

Table 2. Australian usage of dry powdered polymer.

YEAR	LANE KILOMETRES
91/92	22
92/93	28
93/94	10
94/95	4
95/96	26
96/97	35
97/98	50
98/99	66
99/00	62

STRUCTURAL DESIGN OF PAVEMENTS

The Austroads Design Guide introduced a rational approach to pavement design based on engineering properties of the materials and structural design principles. This is acknowledged as an important advance in design methodology. However, as explained below, not all stabilisation methods are adequately catered for.

The designer uses CIRCLY, (Wardle, 1999) a layered elastic computer program, to calculate elastic strains in the pavements. Selected critical strains are then **empirically** related to observed pavement performance. The vertical compressive strain at subgrade level is related to the repetitions to cause rutting failure, and the tensile strain at the underside of bound layers is related to repetitions to cause cracking. This is called a 'mechanistic', 'rational' or 'analytical' design method. However, it is still largely an empirical method because there is no adequate theory to relate tensile strains to crack formation nor to relate vertical strain at subgrade level to the rate at which surface rutting develops. The last step in the design process remains **purely empirical**. In other words, calibration against actual pavement performance is necessary.

The Austroads empirical formula that relates subgrade strain to rutting life in ESAs is

$$N = (0.008511/\text{subgrade strain})^{7.14}.$$

It was developed from observations of the performance of **unbound** pavements. In the absence of comparable performance observations for stabilised pavements, the same 'unbound' formula is used for predicting the life of stabilised pavements. This was never likely to be fully satisfactory, essentially because the formula could only respond to any increase in stiffness caused by the process of stabilisation. An increased stiffness reduces the subgrade strain and so the formula predicts increased rutting life.

The Austroads rutting design method concentrates on protecting the subgrade from overstressing. The type of failure being guarded against is rutting of the road surface arising primarily from subgrade deformation. Deformation within the basecourse itself is not directly addressed. Yet it is known that when marginal pavement materials are used, much of the surface rutting can be due to basecourse deformation. Stabilised basecourses increase rutting life not only because they protect the subgrade. Improvement is also due to the lower plastic deformations of the stabilised basecourse itself. This is sometimes overlooked now that the move from 'empirical' to 'mechanistic' design methods has put such emphasis on the elastic stiffness (modulus) of pavement materials. High modulus is now often incorrectly accepted as the only measure of a 'good' material even though it deals mainly with load-spreading ability.

Pavement life can also be increased in other ways. It is improved if the stabilisation treatment does not lead to shrinkage and to load-induced cracking of the basecourse. This is because access of surface water through cracks to the subgrade does not occur and also because there are no basecourse cracks to reflect into the overlying, fatigue-prone asphalt or sprayed seals.

Also, in some cases the waterproofing produced by the stabiliser can be more relevant to pavement performance than increased stiffness. For example, where road distress is not primarily due to traffic, but involves environmental cracking of the surface caused by movements in a reactive clay subgrade, stiffening of the basecourse may not be important. Here it is important for the stabilised basecourse to function as an impermeable, non-cracking protection to the subgrade to improve its volume stability. Especially in areas of poor drainage, the treated basecourse should act as a barrier rather than a path to water reaching the subgrade from periodically flooded shoulders.

Thus there are ways in which stabilising methods produce improvements in pavement performance that cannot be explained or quantified in terms of elastic modulus and the Austroads mechanistic design method.

POLYMER-STABILISED DESIGN

As discussed above, polymers act to preserve the considerable dry strength of plastic gravels by a process of internal and external waterproofing. Soaked CBR testing of treated and untreated gravels has been the method most commonly used to indicate the degree of improvement in shear strength achieved for particular gravels. The results for four gravels tested recently by VicRoads as part of their ongoing evaluation of dry powdered polymer are given in table 3.

Although the gravels tested were only moderately plastic (Plasticity Indexes from 5 to 7), the soaked CBRs of the polymer-treated samples are significantly higher than those of the raw (untreated) samples in all four cases. The differences would be expected to be greater for higher plasticity materials.

Largely because the polymer-treated basecourses remain drier in service, they exhibit reduced plastic deformability and so the rate at which wheelpath deformations accumulate is reduced. Repeated load triaxial testing designed to quantify, or at least rank this aspect of performance is planned by VicRoads. To establish relevant moisture contents for test samples, however, the equilibrium in-service moisture contents of treated and untreated basecourse gravel must first be estimated. It is envisaged that this will require moisture sampling from treated pavements that have been in service for some time.

Because polymer stabilised basecourses function as a flexible, low permeability, crack-free protective barrier to the subgrade, the equilibrium moisture condition of the subgrade is likely to be lowered. This would justify an increase in design subgrade CBR and consequently a reduced design pavement thickness. Again, however, the expected reductions in equilibrium moisture content are yet to be confirmed by sampling from treated in-service roads. In this regard, the periodic monitoring of surface deflections undertaken by road authorities might indirectly indicate where reductions in subgrade moisture content have occurred.

To date, decisions to use polymers have been based on the accumulating field evidence of their effectiveness, coupled with the simple capillary rise tests and soaked CBR tests described earlier. For each candidate gravel being considered for treatment, the two tests are used to confirm that polymer produces the expected waterproofing effects.

**Table 3 VICROADS POLYROAD INVESTIGATION.
Soaked CBRs of treated and untreated gravels**

Material	Additive	PI	AS 1289.5.2.1 & 1289.6.1.1*				AS 1141.53**		
			Density Ratio (% Modified)	OMC (%)	CBR (%)	Swell (%)	Capillary Rise (%)	Water Absorption (%)	Swell (%)
Gravelly Sand	Raw	7	98	6	180	0.0	100	9	13
	1.5% Polyroad#		98	6.5	230	0.0	32	2	0
Crushed River Gravel	Raw	5	98	5.5	150	0.0	100	6	2
	1.5% Polyroad		98	5.5	170	0.0	18	2	0
Soft Sandstone	Raw	5	98	8	110	0.0	100	16	19
	1.5% Polyroad		98	8.5	190	-0.1	74	8	2
Ripped & Crushed Mudstone/Sandstone	Raw	6	98	10	60	1.1	100	20	11
	1.5% Polyroad		98	11	100	0.1	86	11	2

Samples cured for 3 days after the addition of Polyroad prior to compaction. Compacted samples cured for a further 3 days prior to 4 day soak.

* AS 1289.5.2.1 – Dry density/moisture content relation of a soil – Modified compactive effort
AS 1289.6.1.1 – CBR for a remoulded specimen

** AS 1141.53 – Absorption, swell and capillary rise of compacted materials.

Note: Polyroad PR21L used.

CONCLUSIONS

Many roads have now been successfully recycled using cementitious products. The fatigue life of cemented layers is, however, sensitive to thickness. Therefore in situations where full design pavement thicknesses cannot be constructed, the maintenance problems associated with fatigue cracking and the high cost of recycling the failed pavements mean that alternative, more flexible stabilisation alternatives should be considered.

Dry Powdered Polymers are especially suited for treating poorer quality, clayey gravels that lose considerable strength if they wet up in service. They have particular application to regions of high water table and where periodic flooding of shoulders occurs.

The Austroads mechanistic pavement design method focuses on pavement stiffness to estimate rutting life. It is not well suited to design polymer-stabilised pavements because polymer improves pavements in ways other than by increasing stiffness. Specifically the benefits of reduced plastic deformability of the drier stabilised layer, an absence of shrinkage and fatigue cracking, and a water barrier over the subgrade are not factored into the mechanistic design method. Consequently designers must currently largely rely on the accumulating field performance evidence to assess the effectiveness of the polymer treatments. Continuing efforts to document the performance of treated pavements are required.

REFERENCES

- AUSTROADS (1992). Pavement Design. A Guide to the Structural Design of Road Pavements, Sydney 1992.
- AUSTROADS (1998), Guide to Stabilisation in Roadworks, Sydney 1998.
- WARDLE, L. J. (1999). CIRCLY Users' Manual, Version 4.0, Mincad Systems Pty Ltd, Richmond, Australia.
- WILMOT, T. (1994). Selection of additives for stabilisation and recycling of road pavements. Proc. 17th ARRB Conf. Gold Coast, 1994.