Technical Report

Ingredients of an Unbound Granular Pavement for a Successful Sprayed Seal

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INGREDIENTS OF AN UNBOUND GRANULAR PAVEMENT FOR A SUCCESSFUL SPRAYED SEAL

by

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ABSTRACT

The design, construction and maintenance of a sprayed seal surfacing are important ingredients to its long term performance. However paramount to achieving such performance is the quality of construction of the underlying pavement structure. In Victoria, 85% or over 19,000 kilometres of the declared rural road network which is managed by VicRoads, is surfaced with a sprayed seal on a pavement constructed utilising unbound granular material. In particular, for pavements carrying up to 8000 heavy vehicles per day which is equivalent to 70 million ESA's, excellent performance has been achieved utilising unbound wet mixed crushed rock as the pavement material. However close attention to its manufacture, supply, delivery and compaction in the roadbed to achieve a dense, tight and uniform surface capable of withstanding hard brooming are also important ingredients to the success of the subsequently applied sprayed seal. This paper discusses the essential ingredients necessary to achieve a strong and stable underlying pavement which in turn provides the best opportunity for a successful sprayed seal surfacing.

1. INTRODUCTION

As sprayed seals form the surfacing on over 30% of the Australian road network, their performance is crucial to the sustainability of that network which in 1999 was estimated to have a value of about $70 billion (ARRB 1999). In Victoria, about 85% or 19,000 km of the declared road network, which is managed by VicRoads, is surfaced with a sprayed seal. A survey of State Road Authorities and Local Government in 1998 (ARRB 1999) showed that in Victoria, average seal life varied between 7 years for 7 mm seals and 12 years for 14 mm seals. In addition, the survey showed that two coat seals achieved little if any additional life relative to equivalent single seals although the former were more likely to have been used in more highly stressed applications. Over the past decade, it had been noted that roads within the Victorian arterial network were being resealed 2-3 years earlier than would have been expected based on their historical performance.

In June 2006, VicRoads convened a forum to examine the reasons for reseals being applied earlier than would have been expected (i.e. to seals less than 7 years old). The forum which brought together representatives of VicRoads and of the sprayed sealing industry in Victoria, were asked to identify causes for the shortened life of seals and to provide suggestions as to how performance may be improved. A key factor that was identified as contributing to the reduced performance was the condition of the pavement at the time of the initial sealing (Midgley and Mangan 2007).

It was clearly evident that the expertise built up over past generations involved in the construction of heavy duty (up to 8000 heavy vehicles per day equivalent to 70 million ESA's) unbound flexible pavements comprising crushed rock had not been adequately transferred to the current generation involved in constructing such pavements nor had the knowledge been very well recorded in guides and publications.

This paper attempts to document the ingredients, when constructing heavy duty unbound granular pavements comprised of crushed rock, essential to achieving a successful spayed seal surfacing.

2. INGREDIENTS

One of the fundamental ingredients for a successful sprayed seal surfacing is a strong and stable underlying pavement structure. If the pavement structure is weak through inadequate pavement design, poor quality materials, poor construction techniques or poor maintenance practices, the sprayed seal surfacing will have reduced life no matter how well the surfacing is prepared. Further, if poor practice is employed when preparing the pavement surface for initial sealing, defects will soon emerge in the applied surfacing in the form of aggregate embedment, stripping and/or flushing.

VicRoads has been at the forefront of constructing successful unbound crushed rock pavements with a sprayed seal surfacing (Peyton 1995). However in recent times, several of the more heavily trafficked rural freeway roads constructed with this type of pavement have experienced difficulties in achieving a long lasting and defect free sprayed seal surfacing.

To achieve a strong and stable pavement constructed with crushed rock and surfaced with a sprayed seal that will successfully carry high volumes of heavy traffic, attention to the following components is required:

2.1 Pavement Design

VicRoads has adopted the Austroads Pavement Design Guide (AP-G17/04) to determine the thickness of pavements constructed with unbound granular materials. For pavements carrying traffic in excess of 10^7 ESA's, a depth comprising 200 mm of crushed rock base course and 200 mm of crushed rock subbase course is required with the remaining thickness comprising appropriate lower subbase materials including any capping material over moisture sensitive subgrades.

2.2 Subgrade Preparation

The preparation of the subgrade must be undertaken such that adequate strength consistent with the pavement design is provided to support the overlaying pavement composition. The strength is usually expressed in terms of its California Bearing Ratio although during construction, the achievement of a specified compacted density in the constructed earthworks is the usual measurement for acceptance of adequate strength. Typical values for compaction vary from a minimum characteristic value of Density Ratio of 99% (6 tests) for heavily trafficked roads to a mean value of 100% (3 tests) for lightly trafficked roads (Section 204); all based on standard compactive effort.

Moisture sensitive subgrades prone to swelling, shrinkage and changes in strength where moisture movement occurs must be separately treated to avoid premature loss of pavement shape and cracking reflecting through to the surface reducing the life of the sprayed seal (Midgley, 1988). Such materials include highly expansive basaltic clay (Plasticity Index greater than 60) and silt soils. In these situations, removal and replacement with non-expansive capping material (Swell Potential < 1.5%) of depths up to 1 metre has been found to successfully minimise the effects of such poor subgrade materials.

2.3 Crushed Rock Requirements

The general requirements for a pavement material including crushed rock are as follows (TB 39) :

- that it is the most economical and fit for purpose material available
- that it should be capable of being spread and compacted (workability) to meet specification requirements
- that it should be durable and not degrade or disintegrate significantly during construction and over the life of the pavement

- that it should have adequate strength to be capable of withstanding the applied traffic and environmental stress and spread the applied load to the subgrade without excessive deformation or rutting during the life of the pavement.

In VicRoads, crushed rock is specified in four different classes as follows :

Class 1 Base for thin bituminous surfaced pavements* (sprayed bituminous seals or hotmix asphalt surfacing up to 60 mm thick).

Class 2 Base for thick bituminous surfaced pavements (hotmix asphalt surfacing greater than 60 mm thick).

Class 3 Upper layers of subbase or as defined in the works specification.**

Class 4 Lower layers of subbase.

* For pavements with a Design Traffic Loading of less than 7×10^6 Equivalent Standard Axles, the use of 20 mm Class 2 crushed rock should be specified subject to proven satisfactory performance.

** For pavements carrying less than 100 heavy vehicles per day, consideration should be given to the use of 20 mm Class 3 crushed rock in base construction provided the material produces sufficient cohesive fines during compaction. 40 mm nominal size material must not be specified for this application.

Note: For all Class 1 and 2 materials and for Class 3 material on roads carrying traffic above 1×10^6 Equivalent Standard Axles, VicRoads always specifies 20 mm nominal size crushed rock.

2.3.1 Economy

For crushed rock to be viable as a pavement material, it must be available, workable, and give satisfactory field performance at the lowest possible cost. The final in-place cost should take into account supply and cartage costs, cost of repair to roads damaged during cartage, spreading and compaction costs and preparation for seal costs.

An example of this is the comparison between a 20 mm and 40 mm nominal sized crushed rock. Although both of sufficient strength, the 40 mm crushed rock is likely to be less costly to supply and delivered to the roadbed than 20 mm crushed rock. However after taking into account the difficulty in spreading and compacting 40 mm crushed rock and the need to avoid segregation, 20 mm crushed is far easier and therefore much cheaper to spread and compact making it a far more economical material to use.

Use of plant mixed wetmixed crushed rock (PMWMCR) is preferred over product supplied “dry” and requiring wetting up in the roadbed. Wetmixed materials are also less likely to become segregated during the delivery and spreading process.

Use of 20 mm crushed rock is also easier to prepare for surfacing and produces a smoother hard dense surface than 40 mm crushed rock.

2.3.2 Workability

Crushed rock must be able to be easily spread and compacted on the roadbed to the required specified standards of shape, level, and density without undue breakdown of particles. Crushed rock produced from softer source rock makes fines during compaction and this should be taken into account when specifying the supply of the product to ensure excessive fines are not produced during final compaction. Excessive fines generated during compaction and during the life of the pavement will result in loss of strength leading to pavement distress which eventually will be exhibited in the condition and life of the sprayed seal surfacing.

Crushed rock produced from granitic sources can produce compaction difficulties arising from the generation of coarse and harsh fine material during the compaction process. Such material is subsequently difficult to prepare for sealing. Quartz rich rock types are also known to have a poor affinity to bitumen particularly in the presence of water. Granitic materials also contain mica which may make compaction difficult due to the flaky and silt size nature of the mica particles which are sensitive to moisture during compaction. Special care during construction is needed when using these materials.

2.3.3 Durability

The resistance to deformation of material throughout the life of the pavement can change with the repeated loading of traffic and the weathering due to the environment. The durability of crushed rock to resist such degradation must therefore be evaluated before use. Tests which have been adopted / developed to identify durable rock from the marginal and poor quality unsound rock are :

- ***Degradation Factor – Source Rock (AS 1141.25.1)***

Used to assess the current stage of decomposition or weathering in igneous (except basalt) and metamorphic source rocks. It gives a measure of the quality and activity of fine particles produced by attrition and dispersion from the surface of the aggregate in the presence of water.

As an example, a sound granitic rock type would have a value of 50 minimum and a range of 35 to 49 for marginal rock.

- ***Secondary Minerals Content in Basic Igneous (Basaltic Type) Rocks (AS 1141.26)***

Minerals are secondary when they have resulted from alteration or reconstruction of the primary rock forming minerals by weathering processes or by other agents. For basaltic rock types, secondary minerals typically take the form of clay or clay like minerals. Materials in this category which have reached a substantial stage of decomposition are unsuitable for use in pavement construction.

A sound basalt rock type would have a value up to 25% maximum and a range of 26 to 30% for marginal rock.

- ***Accelerated Soundness Index (AS 1141.29)***

This test is used to assess the physical degradation of basalt source rock. The principal cause for degradation can be attributed to the swelling of clay minerals, particularly those in the smectite group, in the source rock.

A sound basalt rock type would have a value of 94 minimum and a range of 90 to 93 for marginal rock.

- ***Ball Mill Value (AS 1141.28)***

This test is used to assess the durability of sedimentary source rock either of the argillaceous (clayey) type or the arenaceous (sandy) type. Such rock types are not considered suitable for use in base pavement layers for roads carrying in excess on 1×10^6 ESA's.

A sound argillaceous sedimentary rock type would have a value up to 30 maximum and a range of 31 to 35 for marginal rock. A sound arenaceous sedimentary rock type would have a value up to 45 maximum and a range of 46 to 55 for marginal rock.

For all rock types, there is a production advantage in allowing some quantity of marginal and unsound rock into the product to allow for more economical use of the rock resource. For example, a total of marginal and unsound rock up to 10% maximum would be permitted in base crushed rock with a limit of 5% maximum of unsound rock in the product. Higher amounts of sound and unsound material are permitted in the upper subbase layer.

Quarry investigations (RC 500.00) are an integral part of VicRoads specification and assessment of the quality of quarry products. The investigation includes the visual assessment of the quarry faces and quarry products, sampling of rock from the faces to produce the Reference Specimens and sampling the quarry products to determine sulphide mineralisation, assigned Los Angeles and Polished Stone values. Reference Specimens are classified as sound, marginal and unsound rock and are used in assessing coarse aggregate quality by visual assessment.

Certain sedimentary and metamorphic sources contain high proportions of sulphide mineralisation which, when reduced to the soluble acid state, can cause significant damage to seals and thin asphalt surfacing. The current VicRoads quarry investigation report indicates the presence or otherwise of this mineralisation.

2.3.4 Strength

The strength of crushed rock is a measure of its mechanical interlock which is dependent of its grading and particle shape, cohesion and resistance to moisture ingress. The ideal or target grading for a base crushed rock is based on a formula originally attributed to Talbot and subsequently enhanced by Fuller as follows:

$$P = 100 \, [\, d / D \,]^{n}$$

Where: p = percentage of particles smaller than sieve size d

D = Maximum (or nominal) size of material

n = 0.5 (Fuller maximum density curve)

After considerable investigation and assessment of crushed rock performance during the late 1960’s and 1970’s, a target grading approaching the n = 0.45 curve (Currie and York 1976) to achieve maximum stability was adopted for hard source rock material as measured by the Los Angeles Value (AS 1141.23). However for the softer source rock (LAV 26 or greater), a product with slightly less fine material was found to produce best results.

Care also needs to be taken to ensure that a permeability reversal between successive layers of pavement is avoided. Desirably, subbase crushed rock should be at least ten times more permeable than base crushed rock. This ensures that any moisture that penetrates the seal and base layer is allowed to travel to the lower levels of the pavement profile to the capping or subgrade level where it travels laterally with the pavement crossfall to the subsurface drains.

Particle shape is characterised into four categories; angular, rounded, elongated or flaky. Angular shaped particles produce the best mechanical interlock, rounded particles have inferior compaction and stability properties, and elongated and flaky particles generally produced by poor crushing technique will also be difficult to compact and possibly have reduced service life.

Cohesion is essential to ensure the particles stay bonded together particularly near the pavement surface where wheel loads of heavy vehicular traffic exert tensional stresses into the pavement which can lead to loss of mechanical interlock. Non plastic crushed rocks lack cohesion (refer Figure 1) and are difficult to produce a hard dense surface capable of withstanding hard brooming prior to sealing. If used on the more heavily trafficked roads, non plastic crushed rocks can quickly lead to cracking in the sprayed seal surfacing allowing moisture ingress and consequent potholing. In such cases, it is necessary to introduce a plastic additive during the production stage to increase the cohesion of the product.

Figure 1 : Surface Lacking Cohesion during Brooming

Resistance to moisture ingress is dependent on the nature and quantity of the fine material comprising the product. A non plastic, coarse graded product will be relatively permeable while a slightly plastic well graded product will be relatively impermeable without any noticeable reduction in strength. Impermeable base crushed rocks resist moisture ingress which is particularly important during the life of the pavement when the sealed surfacing inevitably cracks and is left untreated for a period of time through lack of timely maintenance.

2.3.5 Product Characteristics

Depending on the relative hardness of the source rock, base crushed rock product complying with the grading limits shown in Table 1 is required to achieve the required strength and maximum stability provided manufacture is aimed at targeting a value at the centre of the grading envelope for each sieve size (Section 812).

Table 1 : Grading Limits for 20 mm Class 1 or 2 Base Crushed Rock

Sieve Size AS (mm)	Test Value before Compaction	
	Limits of Grading (% Passing by Mass) – LAV= 25 or less	**Limits of Grading (% Passing by Mass) – LAV = 26 or more**
26.5	100	100
19.0	95 - 100	95 – 100
13.2	78 – 92	78 – 92
9.5	63 – 83	63 - 83
4.75	44 – 64	44 - 64
2.36	30 – 48	29 - 48
0.425	14 - 22	13 - 21
0.075	7 – 11	5 - 9

The product must also meet the test requirements shown in Table 2 to ensure strength and workability parameters are provided (Section 812).

Some hard rocks do not produce sufficient fine particles during normal crushing processes to make the grade of crushed rock complying with the requirements of Tables 1 and 2. Fine clayey sand or fine clayey filler additives may be incorporated into the crushed rock mixture to improve its grading and cohesion and/or to reduce its permeability. The total amount of additive permitted should not exceed 15% of total dry mass of the crushed rock product. If clayey filler is used as all or part of the total additive, the total amount of clayey filler additive should not exceed 4% of the total dry mass of the crushed rock product. Additives which are non durable or subject to appreciable breakdown are not permitted.

When additives are included into the product, care needs to be taken to ensure that close control over the additives characteristics including grading and Plasticity Index are monitored and that the material is:

- free of vegetable matter
- screened if necessary to remove all oversize particles, lumps and balls of clay exceeding 10 mm in the case of a clayey sand or exceeding 4 mm in the case of a clayey filler
- stored and maintained in a dry and free flowing state and added to the crushed rock as a separate component at any stage after completion of primary crushing
- distributed into the crushed rock by a method that is capable of verifying that the pre-determined distribution rate has been achieved; and is
- uniformly mixed through the crushed rock by use of a pugmill or other agreed methods.

Various waste products from industrial sources, such as flue dust or precipitator ash from cement works or coal-fired power stations, have also been used to modify the grading characteristics of crushed rock products. Because of the cementitious and/or highly soluble nature of some of these materials, limitations must be placed on their use including not to be used within 200 mm of pavement finished surface level.

Use of unsound and marginal rock not exceeding the percentages specified in Table 3 have also been found to allow better use of the rock source reserves while not compromising the durability of the product. The presence of such materials in the product may also aid compaction without affecting strength (Section 812).

Table 2 : Test Requirements for Crushed Rock Product

Test	Test Value			
	Class 1	**Class 2**	**Class 3**	**Class 4**
Liquid Limit % (max)	30	30	35	40
Plasticity Index (range)	2 - 6 (+)	0 - 6	0 - 10	0 - 20
California Bearing Ratio (%) (min) (++)	-	-	-	15
Flakiness Index (%) (max)	35	35	-	-
PI x % passing 0.425 mm sieve (max)	-	-	-	450
Crushed Particles (%) (min) (+++)	60	60	50	-
Permeability (m/sec) (++++) (max)	5×10^{-8} m/sec	#	##	###

(+) Until the post compaction Plasticity Index is known, the Plasticity Index should initially be targeted to the middle of the range and should be varied to meet the permeability requirement (if applicable) and post-compaction requirements specified in Section 304.

(++) Value applicable to material passing 19.0 mm sieve; initially at optimum moisture content and 98% of maximum dry density as determined by test using Modified compactive effort, but then soaked for 4 days prior to the CBR test.

(+++) Applicable to crushed river gravels if approved for use.

(++++) Value applicable to material passing 19.0 mm sieve; initially at optimum moisture content and 98% of maximum dry density as determined by test using Modified compactive effort. The Contractor shall nominate the target grading and Plasticity Index required to satisfy the specified permeability requirement.

(#) For roads with a Design Traffic Load of $<7 \times 10^{6}$ ESA's, permeability values are normally not required unless it is a specific requirement of the pavement design or there are other specific reasons for inclusion

(##) Not normally specified but where appropriate, must be at least 10 times more permeable than base crushed rock.

(###) Where the works involve placement of pavement material directly over a moisture sensitive subgrade, it may be appropriate to specify a limit of permeability for the Class 4 subbase. A limit of 5×10^{-9} m/sec (max) is recommended.

Table 3 : Unsound and Marginal Rock Content

Class	Total of Marginal and Unsound Rock % (max)	Unsound Rock % (max)
1	10	5
2	10	7
3	20	10
4	-	-

2.3.6 Quality Control

In order to consistently achieve the product requirements describe above, it is necessary to undertake quality control testing at a frequency described in Table 4.

Table 4 : Minimum Frequency of Testing

Test	Minimum Frequency of Testing
Grading - Final Product - Additives	On each production day - One per 500 tonnes or part thereof On each production day - One per 250 tonne or part thereof of additive used
Unsound Rock Content (+)	One per production day of a sample taken from the final product or from individual rock components before blending
Moisture Content - Crushed Rock (++) - PMWMCR	One per production day On each production day - One per 500 tonnes or part thereof
Plasticity Index	**Class 1 Base** In each production week - One per 2500 tonne or part thereof **Class 2 Base and Classes 3 and 4 Subbase** In each production month - One per 5000 tonne or part thereof
California Bearing Ratio (+++)	Prior to the commencement of work and at other times when the nature and/or physical properties of the material have changed
Degradation Factor - Crusher Fines (+)	One per 1000 tonne on each production day
Permeability	Prior to commencement of work and at other times when the nature and/or physical properties of the material have changed
pH and Conductivity (++++)	One per production day
Flakiness Index	One per production month
Crushed Particles (+++++)	One per production month
(+) Not applicable to Class 4 subbase unless otherwise specified (++) Applicable only when payment is to be made on a mass basis (+++) Applicable to Class 4 subbase (++++) Applicable only to sources identified in the current Quarry Investigation Report as containing sulphide/sulphate mineralisation (+++++) Applicable to crushed river gravels	

While VicRoads requires all test results obtained from Table 4 testing to be within specification limits detailed in Tables 1, 2 and 3, producers are encouraged to adopt a statistical basis for control when manufacturing crushed rock. For example, the upper and lower limits of grading as shown in Table 1 should be plotted on a control chart and individual results should then fall within these limits with the moving average of the past ten results being close to the target grading. Any trend away from the target grading may indicate corrective action needs to be taken, e.g. need to replace worn screens; additive material has changed in nature; belt speed for component aggregates needs adjusting.

2.4 Pavement Construction

The adopted practice for constructing pavements may well vary depending on the size and nature of the particular road project. On a large greenfield site, the pavement construction should follow a pattern. This would influence lot size, types and numbers of plant and production rates. The process involves getting a certain quantity of material placed, but not too much that cannot be adequately rolled and trimmed on the same day. It would be expected that further roiling might be required on the following morning to complete the compaction process to specified requirements.

Adoption of such a pattern on smaller jobs under traffic may not be possible. Therefore forward planning and thinking, based on the circumstances is often required. One of the difficulties in dealing with somewhat difficult to place materials is that it is not just the level of expertise in VicRoads that has dropped; it is also the level of expertise in the construction industry generally that is a concern.

The process of constructing unbound crushed rock pavements requires close attention to controlling quality in a number of areas and these are described as follows (Section 304) :

- Wet-mixing crushed rock prior to delivery to the roadbed will assist in minimising segregation during the spreading stage. However the type and capacity of the pugmill will determine the length of the mixing time. Too short a mixing time in the pugmill will result in uneven moisture content throughout the product and will adversely impact on the ability to readily achieve the required compaction result;
- Delivery of the wet-mixed material such that the material arrives at the site at or near modified optimum moisture content (OMC). For long distant hauls or delivery during high temperatures (say over 30^{O}C ambient temperature), consideration should be given to covering the wet-mixed material (refer Figure 2) to minimise the loss of moisture through evaporation at the exposed surface of the heaped material in the truck. This variation in moisture content in the material will affect the compactability of the material leading to variable densities being achieved and hence likelihood of not achieving the specified requirements for acceptance of the lot.

Figure 2 : Delivery of Material with Covered Trucks

- Spreading the wet-mixed material uniformly across the pavement (refer Figure 3) width to a constant depth such that after compaction, the specified layer thickness is achieved. Optimum compaction is achieved with layer thicknesses in the range 100 mm to 150 mm. This requires a knowledge of the loose to compacted thickness ratio and then constant checking of the loose spread thickness by manual means or by use of automatic level control using a Global Positioning System;

Figure 3 : Uniform Spreading of Wetmix Material

- Removing pockets of segregated material (refer Figure 4) prior to compaction and replacing with uniformly graded product. Segregation in the form of an accumulation of the coarser particles often occurs as the material is unloaded from the delivery truck into a windrow and again when the material is spread across the pavement to form the required loose layer thickness. It is important that a homogenous layer of even surface texture is achieved such that the subsequent bituminous prime or primer seal is able to adhere to the constructed granular surface in a consistent manner;

Figure 4 : Boney Segregated Areas

- Use of steel wheeled static rollers for the first pass after spreading followed by approximately four passes of a vibrating steel drum rollers operating at low frequency and high amplitude followed by pneumatic tyred rollers (refer Figure 5) operating with high tyre pressure to knead the surface into a tight, evenly textured finish achieves a condition most beneficial for sprayed sealing;

Figure 5 : Roller Routine using Steel and Pneumatic Tyred Rollers

- Compacting the material to achieve the following standards of modified compaction as shown in Table 5.

Table 5 : Requirements for Lot Acceptance of Compaction

Scale[1]	Characteristic Value[2] of Density Ratio (%)		Mean Value[3] of Density Ratio (%)		Assessment
	Base	Subbase	Base	Subbase	
A1	Not less than 100.0	Not less than 98.0			Accept lot
A2	Not less than 99.0	Not less than 98.0			Accept lot
B	Not less than 98.0	Not less than 97.0			Accept lot
C			Not less than 100.0	Not less than 98.0	Accept lot

NOTES :

1. For major works such as freeways and divided roads with traffic in excess of 7x 10^6 ESA's, Scale A2 requirements should be specified for all base pavement layers except that Scale A1 requirements should be specified for the upper 100 mm of base where the work is to be opened to traffic with a sprayed surface seal.

For medium works such as important undivided arterial roads with traffic in the range 1 to 7x 10^6 ESA's, Scale B requirements should be specified.

For lighter traffic road and minor works, Scale C requirements may be specified.

2. The characteristic value of density ratio of the lot shall be calculated as $\bar{x}$ - 0.92S for six tests per lot where $\bar{x}$ and S are respectively the mean and the standard deviation of the individual density ratio test values for the lot.
   The mean of density ratio is defined by:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

   The standard deviation of density ratio test values is defined by :

$$S = \sqrt{\frac{\sum_{i=1}^{n} (\bar{x} - x_i)^2}{n-1}}$$

   where x_i, i=1, 2, 3, ...n, is the individual density ratio test value and n is the number of tests per lot.

3. For work to be tested for compliance with Scale C requirements, the number of tests per lot shall be three.

- Ensuring the following characteristic values of the product after compaction are checked :

  (1) Grading

  A small increase of 1% to 2% of fine material passing the 0.425 mm and 0.075 mm sieves over that specified in Table 1 is permitted to account for breakdown of the crushed rock particles during the compaction process. However excessive rolling and/or reworking can result in excessive fine material being generated which weakens the resultant product and increases the likelihood of rutting occurring in the top layer of base pavement.

  (2) Plasticity Index

  No increase in PI of the resultant product above that specified in Table 2 is permitted. Any increase over these limits increases the moisture susceptibility of the material weakening the pavement under traffic during wet periods which can lead to distress reflecting through the sprayed seal surfacing. Regular post PI testing of the as-compacted product is therefore essential to guard against this occurrence and supervisors must be prepared to reject any pavement materials that do not meet these requirements.

Other considerations that will assist in prolonging the life of a sprayed seal are :

- provision of low side subsurface drainage where boxed pavements are constructed (refer Figure 6);

Figure 6 : Low Side Subsurface Drain

- sealing over width by 300 mm onto each verge to prevent ingress of moisture down the boxing face;
- sloping the high side verge away from the pavement, again to avoid ingress of moisture; and
- use of double-coat seals as standard practice to ensure the integrity of the pavement.

2.5 Preparation of Pavement Surface

The pavement surface needs to be prepared to produce a hard dense surface capable of being swept with a rotary road broom to leave a tight surface (refer Figure 7) free of loose and foreign materials. Further, the surface so prepared needs to be free of ravelling (refer Figure 8) and should be uniform in texture with no lamination (refer Figure 9) within 75 mm of the finished surface. The surface also needs to be true to the specified shape and level. Pavement surfaces that do not meet these requirements should be rejected and satisfactorily reworked before being accepted as suitable for sealing.

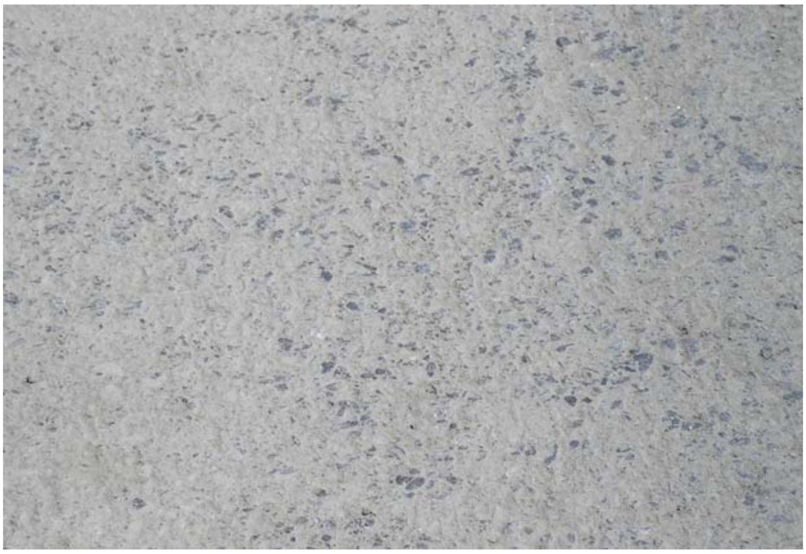

Figure 7 : Well Prepared Surface

Figure 8 : Ravelled Area following Brooming

Figure 9 : Laminated Layer

Where practicable, directing traffic onto the compacted pavement surface prior to sealing is good practice. This will identify any weak or soft areas which may have been missed during proof rolling. However should the surface remain out of specification for ride quality, tyning up the top 50 mm to 75 mm of crushed rock surface and adopting a long grading process (refer Figure 10) without the control of level pegs will produce excellent results provided the loosened material is compacted back to specified standard. Care must be taken however, to ensure against lamination of this reworked layer.

Figure 10 : Long Grade

Should a surface appear “hungry” with a coarse texture, slurrying up with water as part of the long grading process and rolling the moisture out by trafficking or use of pneumatic multi-tyred rollers often achieves good results. However over-working can sometimes produce excessive fines (refer Figure 11) resulting is a “glassy” surface finish which is undesirable for priming purposes.

Figure 11 : Excessive Slurrying of Fines

A critical step in the process when preparing a crushed rock pavement for sealing is to achieve a condition known as dry-back. Dry-back occurs when sufficient moisture has been removed from the compacted and prepared upper base course pavement layer such that a distinctive ring can be heard when hit with the head of a sledge hammer or mattock. Should a dull sound be heard, the pavement has not dried out sufficiently and should not be submitted for sealing. Alternatively testing for moisture content by non-destructive means can be undertaken whereby all results less than 70% OMC and preferably results less than a mean of 60% OMC indicate that the pavement has dried out sufficiently. It should be noted that for granite pavement materials, a period of 3 to 4 days may be needed to achieve the required dry-back condition.

A procedure that is not widely used to asses dry-back utilises the ball penetration (refer Figure 12) test method (AG:PT/T251). This test method describes the procedure for measuring the depth of penetration of a road surface by a steel ball under the impact of a standard load. The results from this test are a measure of pavement hardness and hence an indication of the likely embedment of sealing aggregate into the pavement surface. A good guide for interpreting the results is contained in the Austroads sprayed seal design method (AP-T68/06). While more work needs to be done to relate the results to specific pavement material types (i.e.) crushed rock versus natural gravels versus sandstones, etc., any pavement with a ball penetration value greater than 2mm may result in seal flushing in due course. However, any pavement with a result greater than 4mm should not be sealed and be allowed to further dry-back until a satisfactory result is obtained.

Figure 12 : Ball Penetrometer

2.6 Pavement Maintenance

A fundamental factor that will determine the long term success of a sprayed seal surfacing provided the design and construction of the seal was undertaken correctly, is the ability of the seal to keep moisture out of the pavement. Crack sealing in a timely manner is paramount particularly during the wetter winter months. Any crack that occurs in a seal and is left unattended will quickly turn into a pothole or crocodile cracking when trafficked under wet conditions.

Subsurface drains that have been installed also need to be regularly checked and flushed out to ensure water is not trapped in the drain creating a zone of weakness in the pavement which will soon be exhibited as crocodile cracking in the surfacing.

Finally, table drains need to be regularly cleaned by grass slashing and shrubbery removed to ensure a free draining condition. Poorly maintained drains that hold water will allow soakage into the pavement edge creating a potential weakness close to the outer wheel path of heavy vehicles. This often results in a rutted pavement or aggregate embedment in the surfacing.

3. CONCLUSIONS

VicRoads experience in constructing unbound crushed rock pavements surfaced with a thin bituminous seal was developed over a long period commencing back in the 1950's. In those days many of these pavements were constructed under traffic and involved converting a significant number of moderately trafficked unsealed roads into sealed roads. In the 1970's, this technology was applied to the construction of more heavily trafficked new pavements without the benefit of trafficking during construction and problems were encountered. This paper has attempted to highlight some of the more critical ingredients that were subsequently adopted which resulted in strong, long lasting pavements with a thin bituminous sprayed seal surfacing.

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He is also is a leader in the field of pavement technology with over 18 years experience in pavement research, investigation, testing and design including managing VicRoads GeoPave Department for 4 years. He has been recognised by Austroads for his outstanding achievement of major national significance in the delivery of Austroads objectives in the field of pavement research.

In 2000, he was appointed to his current position as VicRoads Regional Director for Western Victoria where he is responsible for the management and delivery of VicRoads $60 million roads and services program in Western Victoria.

Lance has work closely with industry in the fields of asphalt and bituminous surfacing technology and has made valuable contributions to the production of various guides, specifications and work tips.