Centre for Pavement Engineering Education

Development of a Mix Design Procedure for Basegrade Stabilisation

A thesis submitted by **Scott Young** (201610432)

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ABSTRACT

Regardless of material types used (ie. flexible or rigid), pavement structures typically consist of a wearing surface, a base layer and a subbase layer to protect the subgrade from damage caused by traffic loads. Local government roads in Australia, particularly in urban environments often only have a flexible base layer sitting directly on the subgrade. When the thickness of the existing granular base layer is deemed too thin to satisfy rehabilitation design requirements, the base and subgrade layers are insitu stabilised in a single process. This is termed Basegrade Stabilisation (Young, 2020).

This process has been used infrequently due to a lack of recognition and fear of substandard performance when the subgrade is considered to form part of a rehabilitated pavement structure. National and international literature supports the use of basegrade stabilisation, however no clear mix design procedure exists to guide practitioners when considering the process. The objective of this research was to develop a procedure to enable optimisation of trial mix designs that would satisfy the requirements of a lightly bound basecourse for application in lightly trafficked local government roads.

Through laboratory experimental research, nine pavement types were examined. They consisted of three subgrade materials of medium to high plasticity and subgrade proportions of 20%, 35% and 50% in the pavement structure. Three binder categories were added to the nine pavement types at various application rates. These were lime/cement/flyash triple blends, slag/lime blends and cement/flyash blends after lime pre-treatment. Unconfined compressive strength testing was the principal test used with 72 tests conducted after 28 days of curing. The target strength was 1MPa to 2MPa which resembles a lightly bound material which has been used successfully in lightly trafficked roads since the 1970's.

86% of the experimental research results exceeded 1MPa. The lowest result was 0.3MPa and the highest result was 3.3MPa. For the stabilised materials, Atterberg Limits were also assessed. The 10^{th} to 90^{th} percentile range was 2.6% to 6.4% for linear shrinkage and 2.8% to 7.8% for plasticity index. The average change in UCS regardless of binder type was 0.25-0.5MPa for a +/-1% change in binder application rate. The sensitivity of subgrade type within the basegrade stabilised materials was low. The average change in UCS regardless of binder type or application rate was approximately 0.5MPa for every +/- 15% absolute change in the amount of subgrade included in the pavement.

A mix design procedure has subsequently been developed. It consists of ten mix design trials being made available, based on preliminary assessment of the untreated basegrade structure. Elements for evaluation include percent fines, linear shrinkage, plasticity index and proportion of subgrade.

Multiple recommendations have been presented for further research which will refine the indicative mix design procedure recommended from this research. The identified further work revolves around additional laboratory testing, using additional raw materials, trialling different stabilisation binders and field validation.

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Name: Tom Wilmot

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No research of this magnitude is feasible without the assistance and support of many others. Firstly, sincere thanks must go to Professor Frank Bullen as the unit chair, for his guidance, professionalism and occasional trip down memory lane.

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Several material suppliers contributed resources to enable the laboratory testing to take place, including Boral Quarries at West Burleigh QLD for the supply of gravel samples and Wagners at Toowoomba QLD for the supply of all the stabilising binders (slag, cement, lime, flyash) used in the research. Toowoomba Regional Council & Shadforth Civil willingly supplied samples of subgrade materials which were greatly appreciated.

To Border-Tek Pty Ltd, Jim, Tim and Dan at your Tweed Heads testing laboratory in NSW, I cannot thank you enough for your ongoing support and positive attitude towards this project. For all of the laboratory testing and supply of subgrade material samples, thank you. To Jim, your expert advice on test methods, material behaviours and for executing the testing program so seamlessly, Thank you.

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With any research project that consumes your personal time for months on end, including weeknights and weekends that should be spent with your family, I am forever grateful to Ainsley, Claudia, Isabelle and Jared for graciously accepting that this was just something I had to do.

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GLOSSARY OF TERMS

AC	Asphaltic Concrete
AGPT	Austroads Guide to Pavement Technology
ARRB	Australian Road Research Board
AS	Australian Standard
ATT	Atterberg Limits
Austroads	Association of State Road Agencies Australia and New Zealand
AustStab	Pavement Recycling and Stabilisation Association
Basegrade Stabilisation	A blend of granular pavement material and subgrade material stabilised with a chemical additive to achieve a UCS of 1-2MPa
CBR	California Bearing Ratio
DCP	Dynamic Cone Penetrometer
DESA	Design Equivalent Standard Axle
ESA	Equivalent Standard Axle
GB	General Blend Cement
GGBFS	Ground Granulated Blast Furnace Slag
GP	General Purpose Cement
IPWEA	Institute of Public Works Engineering Australasia
LS	Linear Shrinkage
MDR	Moisture Density Relationship
MPa	Mega Pascals
NSW	New South Wales
PI	Plasticity Index
PSD	Particle Size Distribution
QLD	Queensland
QTMR	Queensland Department of Transport and Main Roads
RTA	NSW Roads and Traffic Authority (no longer used)
TAS	Tasmania
TfNSW	Department of Transport for New South Wales
UCS	Unconfined Compressive Strength
WLS	Weighted Linear Shrinkage
WPI	Weighted Plasticity Index

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1. INTRODUCTION

This research focussed on the development of mix design procedures for an insitu stabilisation process that has already been implemented for many decades in Australia, albeit without a recognised design approach. The process is termed basegrade stabilisation which is defined in section 1.2. The sub sections listed below describe more about basegrade stabilisation as well as an outline of the research approach adopted to quantify the mix design procedures that have been developed.

- Pavement Structures
- Basegrade Stabilisation Defined
- Applications for Basegrade Stabilisation
- Research Objectives
- Research Methods

1.1 Pavement Structures

This research evolved from the necessity of local government authorities in Australia to depart from theoretical standard flexible pavement structures (refer Figure 1), as a way to explore smarter and more cost effective methods of pavement rehabilitation in the local government sector.

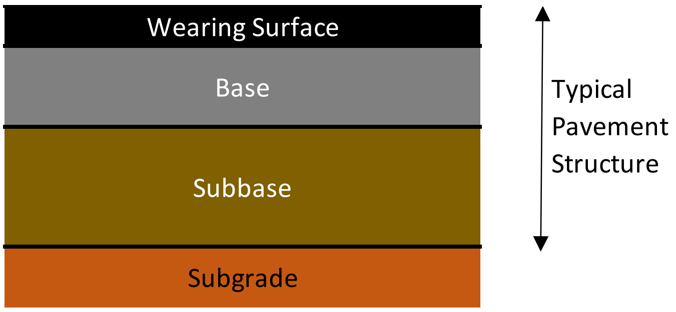


Figure 1. Typical Flexible Pavement Structure (Austroads, 2017)

The 'necessity' was based on the fact that not all road pavements in Australia were originally built with the standard structure shown in Figure 1. Specifically, the subbase layer was often omitted and thin layers of granular base course quality materials were built directly on top of the subgrade in lightly trafficked urban environments, as this was all that was required to support traffic loads of the time. Figure 2 illustrates this notion.

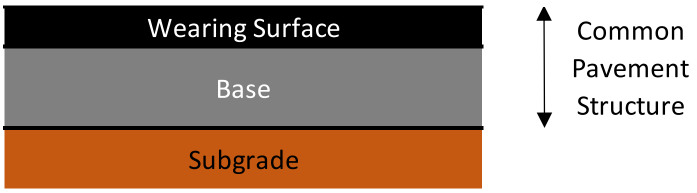


Figure 2. Common Flexible Pavement Structure in Lightly Trafficked Roads

There are many methods of pavement rehabilitation available to asset owners and insitu stabilisation of typical and common pavement structures is one such method that has historically been performed in existing granular base and/or subbase materials or subgrade materials such as clays and/or silts (RTA, 2004). There are well documented design (Austroads, 2017), construction (Austroads, 2019a) and performance (Hodgkinson, 1996) publications covering these processes, albeit only as independent functions where any one of these layers is treated independently of the other. Figure 3 illustrates this 'singular' concept where multiple pavement structure alternatives are presented in this Austroads publication for the application of a stabilised layer as a base course, subbase or subgrade treatment.

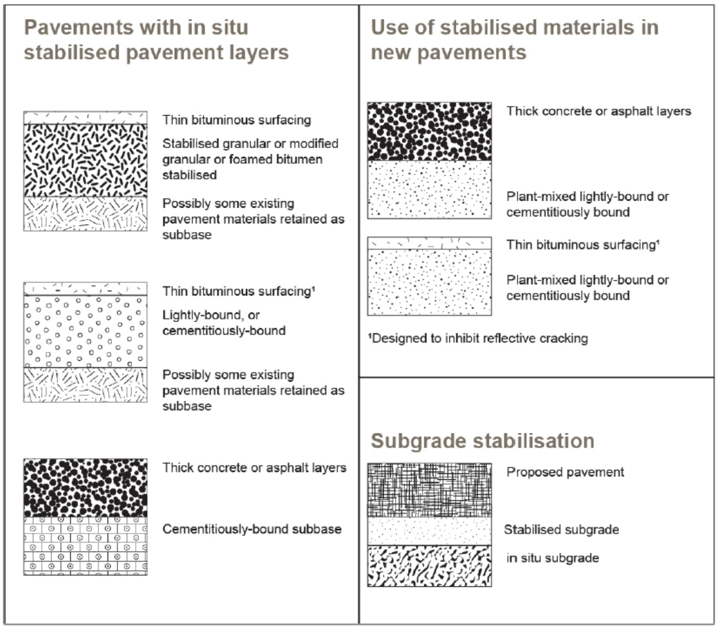


Figure 3. Application of Stabilised Materials (Austroads, 2019a)

Often when common pavement structures are identified for rehabilitation, the absence of a subbase layer results in the base layer having inadequate thickness to recycle using insitu stabilisation based on the requirements to satisfy structural design requirements (eg. a 20 year design life). This challenge however can be overcome by adopting the process of Basegrade Stabilisation in lieu of other more expensive renewal treatments, such as complete removal of all pavement materials and replacement with new imported materials.

1.2 Basegrade Stabilisation Defined

Basegrade stabilisation (Young, 2020) is the process of insitu stabilising existing granular pavement materials that are mixed with subgrade materials and a suitable binder to improve the engineering properties of the combined layers. Basegrade stabilisation occurs when the existing pavement gravels comprising a base course (and/or subbase course) are not thick enough and subgrade materials are incorporated into the granular materials to satisfy the required depth of stabilisation (refer Figure 4 and Figure 5).

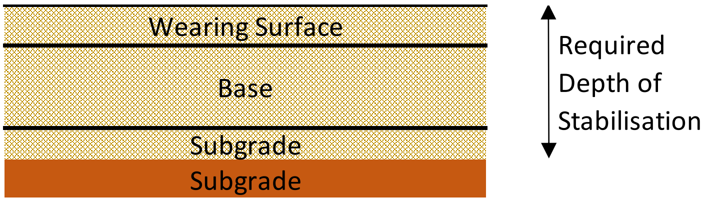


Figure 4. The 'Basegrade Stabilisation' Concept (Young, 2020)

This form of insitu stabilisation is not a common method of pavement rehabilitation, largely due to the lack of published mix design guidance and lack of recognition of the process.

1.3 Applications for Basegrade Stabilisation

There is some evidence from the stabilisation industry (AustStab, 2020) to advocate the mixing of subgrade materials into existing pavement gravels on lightly trafficked roads in the local government sector. However there is no documented protocol to enable mix design optimisation based on the blended properties of the pavement and subgrade materials. This form of multi-layer insitu stabilisation and the gap in mix design protocol forms the basis of this research. The process will be identified as basegrade stabilisation in this research.

The predominant application for basegrade stabilisation in local government is existing roads that have inadequate granular thickness and have been evaluated through structural analysis as requiring a thicker treatment at the time of intervention. Therefore when a site evaluation identifies the deficiency in existing pavement thickness, basegrade stabilisation can be considered. Figure 5 illustrates this where the design thickness exceeds the available thickness of existing pavement material.

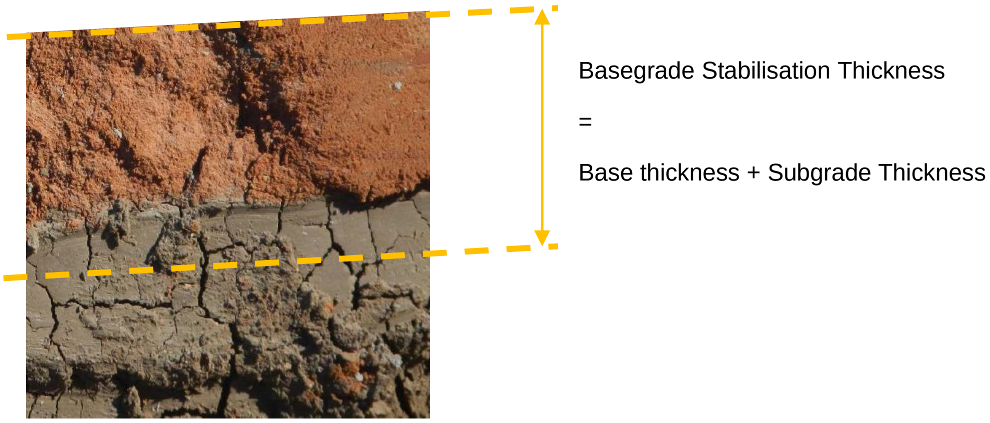


Figure 5. Basegrade Stabilisation Composition (image ref: AustStab, 2020)

The process of selecting of a suitable mix design to satisfy the structural design strength requirements for a basegrade stabilisation treatment have not been specifically documented (Austroads, 2019a). This current gap in the industry means that when a mix design is undertaken with the knowledge that the subgrade will be incorporated into the pavement gravels, the mix design may not produce an optimum outcome in the first instance. This has the risk of one or more of the following consequences:

i) The mix design process takes longer;
ii) Commencement of projects may be delayed;
iii) The mix design process cost increases;
iv) The mix design process does not provide an optimised recommendation, resulting in potentially the incorrect selection of binder type and/or binder application rate;
v) Strength gains achieved during and after construction are too variable which affect the long term performance;
vi) The asset owner does not have faith in the concept of basegrade stabilisation.

The stabilisation industry will benefit from having access to an indicative mix design procedure that considers pavements comprising a variety of subgrade material types as well as variations in proportions of subgrade materials being incorporated into the pavement gravels.

This research will benefit local government engineers, consultants and geotechnical engineers across Australia by providing evidence that blending subgrade materials with pavement granular materials can achieve desired strength outcomes with the application of suitable mix design protocol.

Further, optimisation of the construction process for a basegrade stabilisation treatment using these research outcomes can be determined to specify either a single day or multiple day process. This decision will depend on the properties of the subgrade material and the proportion of the subgrade material being blended into the granular pavement. There is anecdotal evidence from the stabilisation industry that hypothesizes incorporation of some binders in a single day can achieve the desired strength gain (ie. general blend cements typically comprising two individual binder types and triple blends which typically comprise three individual binder types). This is in contrast to other basegrade pavements that due to the higher proportion of subgrade being incorporated and/or the properties of the subgrade being incorporated (eg. highly plastic where the liquid limit exceeds 50%), the construction process requires the lime component of a triple blend to be applied first to ameliorate and flocculate the clay components. This occurs prior to being treated with cementitious general blends, usually the following day.

Subject to implementation of further identified work, a mix design procedure developed for basegrade stabilisation treatments has the potential to be published by relevant industry bodies such as the Pavement Recycling and Stabilisation Association (AustStab), the Australian Road Research Board (ARRB), the Institute of Public Works Engineering Australasia (IPWEA) and Austroads.

1.4 Research Objectives

The research project's main objective is:

- To develop a mix design procedure for basegrade stabilisation treatments on local government pavement rehabilitation projects identified in lightly trafficked environments.

  This will enable pavement engineers and practitioners to systematically select a trial mix design (or designs) for laboratory validation prior to commencement of a project. This procedure will optimise the binder type, binder application rate and the construction procedure based on the properties and proportion of subgrade materials proposed to be mixed into existing granular pavement materials using insitu stabilisation.

  Development of a mix design procedure will consider outcomes from experimental laboratory testing on nine pavement types based on their ability to achieve a target Unconfined Compressive Strength (UCS) of 1-2MPa at 28 days moist curing (TMR, 2020c). The target UCS imitates the current Austroads definition of a lightly bound cemented material (Austroads, 2017) which is a common strength target in the rehabilitation of local government lightly trafficked roads using insitu stabilisation historically (Ritchie, 1993) and in today's pavement rehabilitation environment (AustStab, 2015).

The supporting sub-objective is:

- To optimise the construction timing strategy based on single or multiple day treatment of basegrade stabilisation treatments. Currently in Australia the decision to carry out insitu stabilisation of granular pavement materials that incorporate various proportions of subgrade over one or two days has not been quantified. It is hypothesized that the proportion of subgrade being blended into the base, combined with the consistency limits of the subgrade will dictate this decision. This hypothesis is based on the 24 hour time period that has been adopted to ameliorate the clay particles prior to being treated with a strengthening cementitious binder in order to achieve the target UCS of 1-2MPa.

1.5 Research Methods

The research methods that were used to satisfy the above objectives are set out below.

1.5.1 Literature Review

Background information and a literature review covering international and Australian content has been presented. The literature review focusses on gathering and exploring information on stabilisation categories and stabilisation binders and how they relate to basegrade stabilisation. The importance of establishing a stabilisation mix design and examples where others have carried out basegrade stabilisation with or without mix design protocol to guide them are also examined. The overarching aim in the literature review is to justify the need to develop mix design procedures for practitioners to follow when adopting a basegrade stabilisation treatment. Consideration of other learnings obtained from previous research and/or experiences has also been introduced.

1.5.2 Case Studies

Three case studies from Queensland, New South Wales and Tasmania have been presented that illustrate the current and ongoing use of basegrade stabilisation in local government. The various levels of mix design protocol are detailed which support the demand for mix design protocol to be established.

1.5.3 Experimental Research

A series of laboratory experimental tests have been performed on nine different pavement types, representing variations in subgrade quality and subgrade proportions blended with a single source of granular material, selected to represent an existing base course gravel in a lightly trafficked road. All nine are indicative of basegrade stabilisation practices that could and do occur in the field (Wilmot, 2020).

The primary test was the unconfined compressive strength (UCS) test. The target strength was 1MPa-2MPa measured after 28 days of controlled temperature curing conditions. All testing was conducted in accordance with test methods published by the Queensland Department of Transport and Main Roads. The results obtained were analysed using simple methods of comparing strengths achieved to strength targets as well as comparing strengths achieved to various other properties of the nine pavement types in the untreated and treated condition (ie. with and without addition of stabilising binders).

Development of an indicative mix design procedure for basegrade stabilisation was formed on the basis of the experimental research outcomes. In particular, where trends were identified as being reliable with an acceptable degree of confidence, specific material properties and tests were defined as criteria within the mix design procedure.

2. BACKGROUND INFORMATION AND LITERATURE REVIEW

Information presented in this part of the thesis underpins the justification for the development of mix design procedures for basegrade stabilisation technology. Seven areas have been investigated, being:

- Australia's Local Government Network
- History of Stabilisation in Australia
- Stabilisation Categories
- Lightly Bound Materials in Local Government
- Stabilisation Binders
- Mix Design Procedures
- Basegrade Stabilisation

Each of the above sections have a specific relationship with the research objective.

2.1 Australia's Local Government Road Network

With the total road network in Australia being approximately 900,000 kilometres in length (White, 2006), roads managed by local government comprise around 75% of this, or 662,999km (Australian Local Government Association, 2019). These are the most valuable assets for local councils to manage, being more than double the value of the next valuable asset classes of buildings, stormwater and wastewater (Australian Local Government Association, 2019). Yet as a mature society we continually observe quantitative evidence published in magazines, engineering journals and presented at industry conferences, detailing the ongoing shortfall of funding available to local government to adequately maintain this asset class. A 2012 New South Wales Institute of Public Works Engineering Conference (NSW IPWEA) paper reported 70% of urban councils did not have enough funding to renew or upgrade their assets (Young, 2012). In 2019 it was reported that of all taxation revenue collection by Australian governments, only 3.6% is allocated to roads in the local government sector (Australian Local Government Association, 2019).

In recent years there has been a significant focus on improving the construction industry's sustainable footprint through the increased use of recycled materials in road making materials, not only to reduce our carbon footprint, but ultimately to reduce costs. LinkedIn (LinkedIn, 2020) is a rapidly growing digital platform with an exceptionally high reach to business professionals (Iqbal, 2020). An extract from a recent LinkedIn post by QLD TMR's Director General is shown in Figure 6 to demonstrate this sustainability focus.

Figure 6. TMR LinkedIn Sustainable Roads Promotion (Scales, 2020)

The approach of using existing road maintenance techniques and slightly altering the input variables (eg. adding glass or plastic to asphalt) is essentially the same approach as basegrade stabilisation. An existing road maintenance technique that has the input variables slightly adjusted from conventional stabilisation techniques, by adding some of the subgrade into the base.

If basegrade stabilisation can be used more widely upon acceptance of a mix design procedure to optimise the probability of success, then local councils will have another way to sustainably manage their most valuable asset at a lower cost to the community.

2.2 History of Stabilisation in Australia

Although pavements in Australia have been rehabilitated since the 1950's (Wilmot, 1994) using insitu stabilisation, the unconventional method of adopting basegrade stabilisation has been far less common and sometimes considered a prohibited practice by many practitioners compared to conventional stabilisation practices that focussed on treatment of specific material layers (eg. subgrade or basecourse).

Stabilisation of defence bases by the Americans during World War II was the first known occurrence of soils being treated with chemical additives to improve their intrinsic properties (RTA, 2004). Airfields and service roads were also constructed using stabilisation technology by the Australian Army in the 1940's (Ritchie, 1993). Coincidently, 1943 was reported to be the first time stabilisation was used in neighbouring New Zealand (Opus International Consultants Limited, 2017).

Around 1950, Stabilisers Limited commenced commercial operations on various projects in multiple Australian states (White, 2006). North Sydney Council in New South Wales is one of the earliest known urban local government organisations to have initiated pavement recycling through stabilisation in the 1950's (Ritchie, 1993). In the 1970's and 1980's extensive stabilisation programs were carried out in Sydney's western suburbs, some of which had annual volumes in excess of 100,000m^2 (Wilmot, 2020). During the 1980's, Brisbane City Council recycled over one million square metres of their road network using cementitious basecourse stabilisation (Condric & Stephenson, 2015).

Some of the urban projects that were stabilised included the old pavement material and various percentages of clay subgrade due to an insufficient thickness of the existing base and no subbase. Whilst there many published forms of evidence detailing the success of these stabilisation programs in terms of long term performance (Hodgkinson, 1996; Vorobieff, 1998; Chakrabarti, et al., 2002; Young, 2012; Condric & Stephenson, 2015), there is no published data to quantify the effectiveness from inclusion of various percentages of subgrade incorporated into the pavement structure, including consideration of using blended binders to improve performance.

In 2001, a survey completed by 162 Australian councils revealed around 80% had insitu stabilisation as a suitable rehabilitation method as part of their maintenance strategy. However a more realistic 30% were actually regular users of chemical and mechanical stabilisation methods. This aligns with the author’s opinion on todays’ use of stabilisation by local government authorities based on 20 years of experience in most states. Consequently, it is obvious that there is an abundance of asset management capacity within local councils to undertake more pavement recycling and leverage off the successes of others, particularly in urban areas of lightly trafficked environments where existing pavements are often considered too thin or too close to the subgrade to stabilise effectively.

In 2020, stabilisation of local roads continues to be a front line rehabilitation treatment strategy by many local councils across the country. Bundaberg Council in Queensland is one such Council that annually treats in excess of 100,000m^2 of their rural road network by cementitious base course stabilisation. Sutherland Council is New South Wales is another regular user of pavement recycling where nearly 20 urban residential roads are stabilised each year, ranging from sub-arterial collectors to low volume cul-de-sac streets.

2.3 Stabilisation Categories

Material characterisation of stabilised materials can take multiple forms based on the type of binder incorporated into the host material, the quantity of binder added and the relative reaction and subsequent strength gain obtained. Stabilisation categories are typically differentiated as material improvements in the subgrade or earthworks layers, or material improvements within the pavement layers (Austroads, 2019a).

2.3.1 Earthworks & Subgrade Stabilisation

Stabilisation of the subgrade or earthworks is generally undertaken to improve the strength and/or provide a working platform to enable construction of the overlying pavement. Improvements in the host material are commonly measured by CBR and sometime UCS as shown in Figure 7 (Austroads, 2019a).

Category of stabilisation	Indicative laboratory strength after stabilisation	Binders adopted	Anticipated performance attributes(5, 4)
Subgrade and formation treatments			
Stabilised earthworks materials	1 < UCS(2,3) ≤ 2 MPa or CBR(1)	• Lime and/or cementitious binder (high plasticity soils) • Cement and/or cementitious binder (low plasticity soils)	• Improved constructability • Improved subgrade CBR and modulus • Improved shear strength • Reduced heave and shrinkage

Figure 7. Subgrade and Earthworks Stabilisation Category (Austroads, 2019a)

The state road authorities adopt various terminologies for earthworks and/or subgrade stabilisation, such as capping layers, select material zones and improved layers. Fundamentally though, they are all associated with providing a support function to the overlying pavement.

2.3.2 Pavement Stabilisation

In pavement layers, material improvements are undertaken by adding a variety of binders to achieve different scales of strength.

Granular stabilisation is when the binder is another granular material, blended with the host granular material to improve properties such as the shear strength, grading and plasticity index and CBR targets often exceed 30% (Austroads, 2019a).

Other forms of stabilisation where multiple properties are also improved are via the addition of a chemical binder such as cement, lime, flyash, slag, bitumen or combinations of these. The resulting strength measured by unconfined compressive strength (UCS) is what determines the stabilisation category. Modified stabilisation is when the 28 day cured UCS does not exceed 1MPa. Lightly bound is when the strength gain is between 1MPa and 2MPa. Bound stabilisation is when the strength gain exceeds 2MPa (Austroads, 2019a). Each of the categories possess slightly different properties and material behaviours (eg. tensile strength, rut resistance, moisture resistance).

These categories from the Austroads suite of Pavement Technology Guides are illustrated in Figure 8.

Category of stabilisation	Indicative laboratory strength after stabilisation	Binders adopted	Anticipated performance attributes(5, 4)
Pavement material treatments			
Granular stabilisation	CBR(1) > 30%	• Blending other granular materials which are classified as binders in the context of this Part	• Improved pavement modulus • Improved shear strength • Improved resistance to aggregate breakdown
Modified materials	UCS(2) < 1 MPa	• Addition of small quantities of cement or cementitious binder • Addition of lime • Addition of chemical binder	• Improved long-term rut-resistance • Improved pavement layer modulus after curing • After curing, reduced sensitivity to loss of strength due to increasing moisture content • Similar to unbound granular materials, moisture content prior to sealing needs to be limited to inhibit premature distress • At low binder contents can be subject to erosion where cracking is present
Lightly-bound cemented materials	1 ≤ UCS(3) ≤ 2 MPa	• Addition of small quantities of cementitious binder, commonly less than 3% binder	• Greater rut-resistance than modified materials • May be susceptible to fatigue cracking but cracking finer than bound materials • At low binder contents can be subject to erosion where cracking is present
Bound cemented materials	UCS(4) > 2 MPa and/or flexural modulus and flexural strength	• Addition of greater quantities of cementitious binder, commonly binder content of 3% or more	• Increased pavement modulus • Thickness design needs to consider susceptibility to fatigue cracking • Some binders introduce transverse shrinkage cracking

Figure 8. Categories of Stabilised Materials for Pavements (Austroads, 2019a)

2.4 Lightly Bound Materials in Local Government

Materials characterised as lightly bound are those which develop a UCS of 1-2MPa after 28 days of ambient temperature curing (Austroads, 2019a). This category of stabilisation is the most common category adopted by local government organisations, particularly on their light trafficked roads. Lightly trafficked flexible pavements are as those that have the capacity to carry up to 1,000,000 design equivalent standard axles (Austroads, 2017). Whilst this definition is heavily influenced by the number and frequency of heavy vehicles that traverse the subject pavement, typical examples include minor roads with one or two way access, local access roads, collectors and local industrial roads with and without buses (Austroads, 2017).

Lightly bound materials are seen to be beneficial as they provide at least the same improvements as modified materials (rut resistance, moisture resistance), but do not produce the higher tensile strains developed by bound materials used in heavier trafficked situations (Austroads, 2019a) and offer reductions in pavement thickness during pavement structural modelling evaluations.

Development of a lightly bound material based on the target UCS strength of 1-2MPa is achieved with the addition of a certain quantity of binder. Austroads suggests only small quantities are required, up to 3% to ensure higher strengths are not developed (Austroads, 2019a). This 'suggestion' is not always appropriate for many local council roads that exhibit marginal or lower quality materials in the base course layer and therefore require higher binder contents to achieve a lightly bound strength range. Further, when a base course material is blended with a portion of subgrade material, the quality of the untreated blend is reduced in comparison to the base material. Often an increase in plasticity index, a finer grading being produced and a lower CBR are observed as a result of the incorporation of the weaker subgrade. Hence higher quantities of appropriate binders are generally required to satisfy the lightly bound strength range.

In essence it is the strength target that is more important to focus on during the mix design phase of a stabilisation project, rather than the amount of binder that is required. At least two binder application rates tested during the mix design phase allows a plot to be generated so that interpolation can occur for selection of the most appropriate binder application rate.

Austroads provide further guidance as to the suitability of host materials based on the plasticity index and particle size distribution. Upper limits of 10% for PI and 25% passing the 0.075mm sieve are recommended, otherwise host materials that do not meet these criteria are considered unsuitable for lightly bound stabilisation (Austroads, 2019a), unless a preliminary treatment with lime for example is undertaken to reduce the PI.

There are numerous examples from Australian local government organisations who over time have published lightly bound strength limits for their road rehabilitation programs. In 1970, 1.5-2.0MPa was recorded as a successful strength produced by stabilisation in local government for several council authorities (Hodgkinson, 1996).

Paul Ritchie was an early pioneer of stabilisation in western Sydney at various councils during his career. He advocated 1.5-2.0MPa was the ideal strength range for stabilisation of lightly trafficked streets that were trialled at Holroyd Council initially in Greystanes (Ritchie, 1993). The success of Ritchie's stabilisation trials led to a more formal publication of this strength target (in 'Step 8') which saw Holroyd Council's 'Road Recycling by Stabilisation' project produce a checklist for first time users of stabilisation (Ritchie, 1993).

A performance study was undertaken in 1997 at Lake Macquarie City Council in NSW on 10 sites that had been stabilised with target strengths of 1.5-2.0MPa using 80/20 cement/flyash blends (Vorobieff, 1998). The sites were existing pavements that were rehabilitated using insitu stabilisation and were situated on clay subgrades with design CBR values ranging from 2% to 13%. The performance study reported a 90% level of success based on the ability of the pavements to achieve the 20 year design life according to deflection test data (Vorobieff, 1998).

AustStab's 2012 Technical Note on 'Cement Stabilisation Practice' also recommends 1-2MPa as being the ideal strength target for lightly bound materials which creates economically viable solutions (AustStab, 2012). Further, these materials enable the use of thin bituminous wearing surfaces to be applied instead of thicker cover arrangements to absorb reflective cracking of otherwise more 'brittle' treatments.

Design guidelines published in New Zealand refer to various stabilisation categories and similarly to Australia, their lightly bound category is one that achieves a UCS between 1MPa and 2MPa (Opus International Consultants Limited, 2017).

With many authorities and publications recommending ranges between 1MPa and 2MPa for lightly bound materials, there was an acknowledgement that strength testing should be carried out after 28 days curing, as many projects were being completed with slower setting binders (Wilmot, 1994). 1.7MPa after 7 days curing was found to be correlated to 2MPa after 28 days, however this was only for a specific binder type and specific host material (Wilmot, 1994).

An earlier Austroads version of the current stabilisation mix design procedures stipulated that 1.5-2.0MPa was a reasonable target for lightly bound materials after 7 days ambient temperature curing for General Purpose (GP) and General Blend (GB) cement binders (Austroads, 2002). However there remains uncertainty in the industry about the reliability of 7 day strength testing particularly when slow setting binders are used, whether it be at ambient temperature or accelerated temperature curing (Austroads, 2002).

The south western district of QLD TMR note that in addition to lightly bound materials providing reduced sensitivity to moisture, they remain suitable for early trafficking (Waters, 2018) which is an important aspect in any road rehabilitation project. They define lightly bound materials as having a UCS of 1.5MPa which is often achieved with binder application rates of 1-2% after 28 day cured samples of quarry manufactured good quality crushed rock (ie. Type 2.1 and Type 2.3 base materials) are tested.

It is therefore evident that the ongoing use of lightly bound materials with a target UCS of 1-2 MPa is reasonable for this research work based on historical and current practices in local government across Australia (AustStab, 2012; Austroads, 2002, 2017, 2019a; Hodgkinson, 1996; Ritchie, 1993; Opus International Consultants Limited, 2017; Waters, 2018; Wilmot, 1994; Vorobieff, 1998).

2.5 Stabilisation Binders

Binder selection for a stabilisation project is extremely important for a number of reasons. The cost of the binder can be up to 50% of the total project cost in some cases and is therefore a significant portion of the project expenditure. Selecting the wrong binder can be a costly judgement.

The role of the binder is to act as a catalyst for a chemical reaction between the host material and the binder that ultimately results in changes to engineering properties of the host material. The effectiveness of the chemical reaction combined with the type of binder and quantity of binder mixed into the pavement material affects the success of the desired improvements.

There are numerous binders available in the Australian stabilisation market, predominantly founded with either cement or lime with supplementary waste products such as flyash and/or ground granulated blast furnace slag (GGBFS). Other binders such as bitumen and polymers are widely accepted and used, but are not being evaluated in this research. Similarly, the use of granular materials for the purpose of mechanical stabilisation to improve particle size distributions, reduce plasticity etc. are not covered in this research. Minimum standards of quality are well documented for the manufacture, storage, transport and use of stabilisation binders. These are shown in Table 1.

Table 1. Binder Standards (Austroads, 2018)

Binder	Australian Standard
Lime	AS1672.1
Cement	AS3972
Slag	AS3582.2
Flyash	AS3582.1

Depending on the location of the project and the source of the individual binder component, a wide selection of cementitious blends can be formulated to treat pavement materials. This multitude of options was termed 'designer blends' by one of Australia's most respected stabilisation practitioners (Wilmot, 1994). Figure 9 is not a complete list of available blends available today as the list was provided by a single product supplier. The product names are also proprietary and do not represent exclusive supply rights, as any supplier with blending capabilities can produce these blends. Other triple blends comprising lime/cement/flyash which are not shown in Figure 9 are proving popular in some states (AustStab, 2020). Another popular binder used in a lot of cementitious stabilisation projects is a 70/30 cement/flyash general blend.

Slag/lime blends	
Stabilment	85% slag, 15% lime
30 lime blend	30% slag, 70% lime
50 lime blend	50% slag, 50% lime
60 lime blend	60% slag, 40% lime
70 lime blend	70% slag, 30% lime
Cement/fly ash blends	
road pozzolan	75% SL cement*, 25% fly ash
road pozzolan 20	80% SL cement*, 20% fly ash
road pozzolan 50	50% SL cement*, 50% fly ash
pozzolan blend 10	90% SL cement*, 10% fly ash
Slag/cement blends	
SSC40	60% slag, 40% SL cement*
SSC50	50% slag, 50% SL cement*

Cement/lime blends	
80/20 blend	80% slag/lime, 20% lime
50 cement blend	50% slag/lime, 50% lime
Fly ash/lime blends	
50 ash blend	50% fly ash, 50% slag/lime
75/25 ash/lime	75% fly ash, 25% lime
Triple blends	
523 slag t blend	50% slag, 20% lime, 30% fly ash
532 slag t blend	50% slag, 30% lime, 20% fly ash
352 lime t blend	30% slag, 50% lime, 20% fly ash
622 cement t blend	60% SL cement*, 20% slag, 20% fly ash
225 ash t blend	25% slag, 25% lime, 50% fly ash
424 triple blend	20% slag, 40% SL cement*, 40% fly ash
442 triple blend	40% slag, 40% SL cement*, 20% fly ash
424 slag triple blend	40% slag, 20% lime, 40% fly ash

Figure 9. Cementitious Binder Options (Austroads, 2018)

Three binder categories have been trialled in this research. They comprise triple blends containing lime/cement/flyash, slag/lime blends and cement/flyash blends with a lime pre-treatment incorporated 24 hours prior to the introduction of the cementitious blend.

Of the eight triple blends illustrated in Figure 9, they all contain a proportion of slag. The minimum amount of lime required in the blend to enable pozzolanic reactions to occur with the slag or flyash elements is 12-15% (Australian Slag Association, 2002). However when high clay contents exist, the lime component is recommended to be increased to as much as 50%. This recommendation has been adopted in this research with some trials exploring 50% lime in the binder blend.

A comprehensive oral history program commissioned by the Roads & Traffic Authority of NSW (now Transport for New South Wales, TfNSW), was underpinned by interviews of then current and retired engineers, contractors, binder suppliers and consultants (RTA, 2004). One of the interviewees was Greg Johnson who at the time worked for Rocla, a concrete products supplier who also manufactured and supplied powdered chemical binders. Johnson’s interview revealed information supporting the foundation of triple blends in Australia in the early 1990’s. He explained that Rocla were looking for a competitive edge in the market and decided to trial blends of more than two binders as they had silo storage capacity for at least three different binders. Hence the triple blend was allegedly born.

Studies into the effectiveness of triple blend binders soon emerged. It was reported that triple blends did indeed provide enhanced properties to treated materials over and above traditional general blend cements comprising cement and flyash (Bullen & Suciu, 1991). The triple blend investigated in this early 1990’s study was a slag/flyash/cement which was found to provide positive attributes around strength gain and working time. However it is recognised that this study was limited to evaluating the performance of a single triple blend on base and subbase materials (ie. a quarry produced crushed rock) and did not include subgrade portions.

A survey sent to 455 councils across Australia in 2001 revealed the most common binders used for base course stabilisation was a cement/flyash blend (Chakrabarti, et al., 2002). Sydney councils in NSW were the only users at the time of triple blends, comprising 60/20/20 cement/slag/flyash and 30/50/20 slag/lime/flyash. It is understood that these triple blends are not as popular today (Wilmot, 2020). The main reason being the councils that used these triple blends have since slowed their rate of pavement recycling. Other more prominent binders being used by current NSW stabilising councils are general blend cements (eg. 75/25 cement/flyash) and slag/limes of varying proportions. QLD also has strong experience over multiple decades using 75/25 cement/flyash blends, along with 60/40 cement/flyash and 60/40 slag/cement blends in some south west regions (Waters, 2018). 70/30 cement/flyash blends are also commonly used with a view of obtaining working time and commercial benefits from the slightly extra flyash component.

Triple blends have become popular in QLD in the last 10 years with two blends comprising lime/cement/flyash being used almost exclusively when the granular layer being stabilised is mixed with an underlying lower quality material that results in a PI between 10% and 20% (AustStab, 2020). A linear shrinkage of 6% is the trigger for adoption of either 30% lime (LS<6) or 40% lime (LS>6).

Wilmot (1994) reported that gravels with high proportions of clay content could be successfully stabilised when the appropriate mix design and binder is selected. Example binder types reported in high clay content gravels were 50/30/20 lime/flyash/slag triple blends and 50/50 slag/lime general blends. Wilmot’s reproduced illustration in Figure 10 demonstrates the effectiveness of selecting the correct binder type, which in this case highlights optimum strength gain when the lime content was 40% of the slag/lime blend. This is in contrast to popular belief that the 85/15 slag/lime is often the most suitable of the slag/lime family, however this is founded on high volume use in granular materials where the clay content was not high. The 60/40 slag/lime blend portrays one of the binders used in this research.

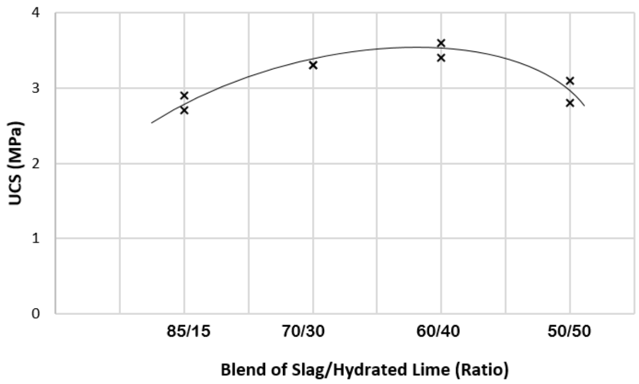


Figure 10. UCS v Lime Content in Slag/Lime Blend (reproduced from Wilmot, 1994)

It is therefore evident that the selection of the three binder categories used in this research reflect commonly used binders across various parts of Australia that have been implemented for many years. It is also clear that selection of an appropriate binder for use in a basegrade stabilisation project requires careful consideration due to the variety of binder types available and the various material characteristics expected to be observed with the research pavements.

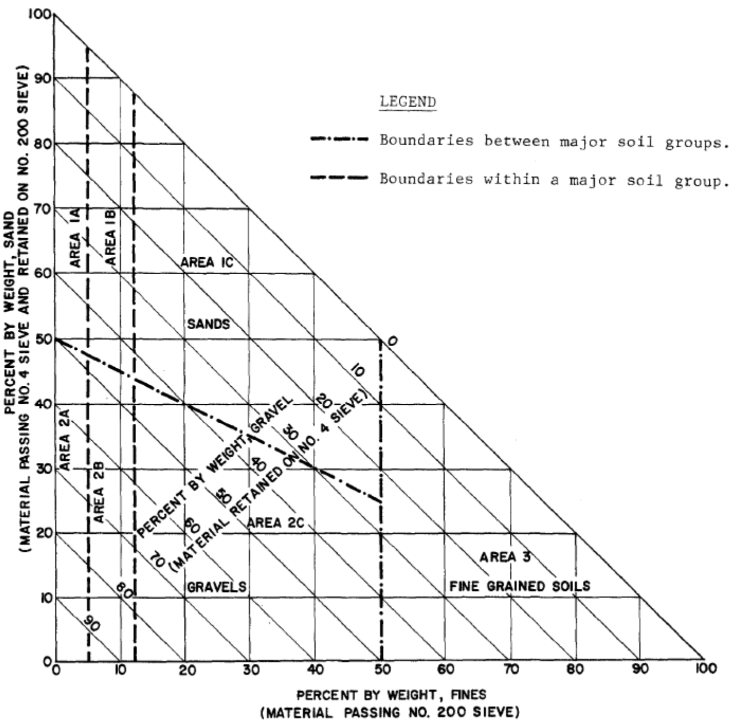
2.6 Mix Design Procedures

A mix design in the context of pavement stabilisation is simply the determination of a binder type and the quantity of that binder to specify for use. This is a relatively straight forward task, however optimisation of a mix design requires further evaluation and engineering judgement to specify the binder type that is not only geographically available and commercially viable, but is able to react appropriately with the host material and produce the required strength or other engineering improvements with the minimum amount of that binder as possible.

2.6.1 International

In the United States, the Department of the Army Corps of Engineers have utilised stabilisation technology for many decades during multiple wars and conflicts. In the mid 1980’s, they published a stabilisation manual that was considered to be ahead of its time in terms of the engineering guidance provided to engineers building army facilities (US Army Corps, 1984). This manual contains comprehensive advice on mix design protocol. The underlying basis is founded on assigning a classification to the host material using a ‘soil triangle’ (refer Figure 11) which is a function of particle size distribution passing the 0.425mm (No. 4) and 0.075mm (No. 200) sieves.

Once the material classification has been made and aligned with the unified soil classification system and consistency limits (liquid limit and plasticity index), recommended binder types are provided in tabular form (refer Figure 12). This approach is independent of whether the material being classified is considered to be a base, subbase or subgrade and is directly related to the material properties. This concept resembles the proposed development of mix design procedures for basegrade stabilisation where the focus for binder selection is related only to the properties of the base/subgrade blend and not specific materials identified within the separate layers.



U.S. Army Corps of Engineers

Figure 11. Soil Gradation Triangle (US Army Corps, 1984)

Area	Soils Class.[a]	Type of Stabilizing Additive Recommended	Restriction on LL and PI of Soil	Restriction on Percent Passing No. 200 Sieve[a]	Remarks
1A	SW or SP	(1) Bituminous (2) Portland Cement (3) Lime-Cement-Fly Ash	 PI not to exceed 25		
1B	SW-SM or SP-SM or SW-SC or SP-SC	(1) Bituminous (2) Portland Cement (3) Lime (4) Lime-Cement-Fly Ash	PI not to exceed 10 PI not to exceed 30 PI not less than 12 PI not to exceed 25		
1C	SM or SC or SM-SC	(1) Bituminous	PI not to exceed 10	Not to exceed 30 percent by weight	
		(2) Portland Cement (3) Lime (4) Lime-Cement-Fly Ash	----b PI not less than 12 PI not to exceed 25		
2A	GW or GP	(1) Bituminous (2) Portland Cement			Well-graded material only Material should contain at least 45 percent by weight of material passing No. 4 sieve
		(3) Lime-Cement-Fly Ash	PI not to exceed 25		
2B	GW-GM or GP-GM or GW-GC or GP-GC	(1) Bituminous (2) Portland Cement	PI not to exceed 10 PI not to exceed 30		Well-graded material only Material should contain at least 45 percent by weight of material passing No. 4 sieve
		(3) Lime (4) Lime-Cement-Fly Ash	PI not less than 12 PI not to exceed 25		
2C	GM or GC or GM-GC	(1) Bituminous	PI not to exceed 10	Not to exceed 30 percent by weight	Well-graded material only
		(2) Portland Cement	---b		Material should contain at least 45 percent by weight of material passing No. 4 sieve
		(3) Lime (4) Lime-Cement-Fly Ash	PI not less than 12 PI not to exceed 25		
3	CH or CL or MH or ML or OH or OL or ML-CL	(1) Portland Cement	LL less than 40 and PI less than 20		Organic and strongly acid soils falling within this area are not susceptible to stabilization by ordinary means
		(2) Lime	PI not less than 12		

[a] Soil classification corresponds to MIL-STD-619. Restriction on liquid limit (LL) and plasticity index (PI) in accordance with Method 103 in MIL-STD-621.

[b] $PI \quad 20 + \frac{50 - \text{percent passing No. 200 sieve}}{4}$

U.S. Army Corps of Engineers

Figure 12. Binder Selection Table (US Army Corps, 1984)

The manual also notes two host material properties and their relationship to the suitability of a material for positive reactions with triple blends, namely lime/cement/flyash which is one of the binders used in this research. The first property is the particle size distribution which has an upper limit of 12% passing the 0.425mm sieve. The second property is the plasticity index which has an upper limit of 25%. These variables have been considered in this research.

Dallas Little is a well-known Texan engineering professor in the field of lime stabilised materials. Arguably, his most famous publication the, 'Handbook for Stabilization of Pavement Subgrades & Base Courses with Lime', or more commonly known as '*the blue book'*, provides a significant wealth of informative literature on lime stabilised materials (Little, 1995). In 2009, Little authored an extension of '*the blue book'* with a report that recommended mix design procedures for selection of binder types and binder application rates for use in pavement base courses and subgrades (Little, 2009).

The report presented various mix design methods in the form of flowcharts, based on host material characteristics, consistency limits, particle size distribution and strength targets. Binder options included lime, cement, and flyash. Whilst Little is internationally regarded for his work, this report continues with a certain theme presented from the 1995 '*blue book'* whereby material characterisation from a mix design perspective must be categorised as either a base course or subgrade. The report recommended that evaluation of host material properties based on particle size distribution and plasticity index is conducted first. The decision tree in Figure 13 was produced from text within the Little (2009) report.

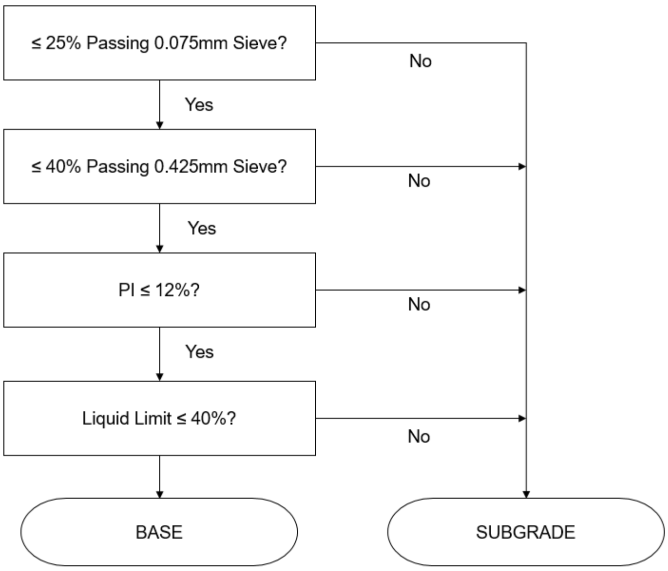


Figure 13. Categorisation of Base Course or Subgrade (produced from Little, 2009)

A flowchart or 'decision tree' for either base course or subgrade materials follows to conclude in a variety of suitable binders for selection (refer Figure 14 and Figure 15). Binder application rates are determined through further laboratory testing on the project specific materials.

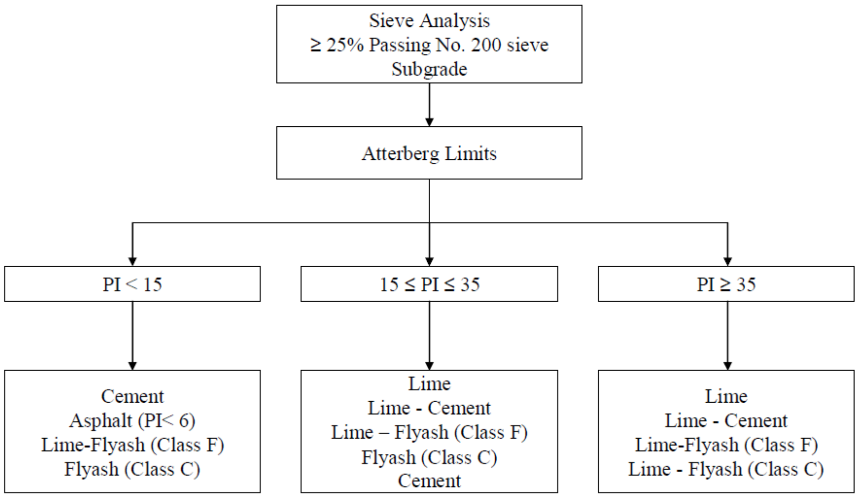


Figure 14. Mix Design Flowchart for Subgrade Materials (Little, 2009)

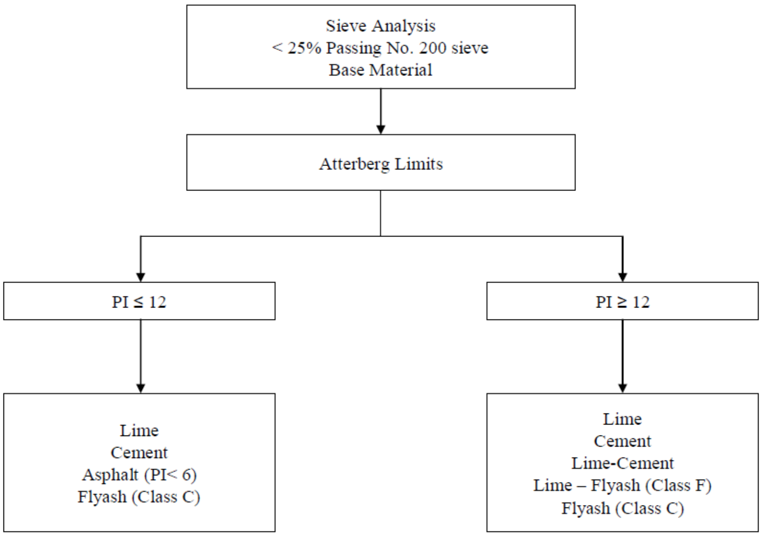


Figure 15. Mix Design Flowchart for Base Course Materials (Little, 2009)

This delineation may possess benefits from the point of verifying strength targets to align with structural design modulus assumptions and understanding layer behaviour, but it restricts the ability to think purely in terms of the materials proposed to be stabilised. A mix design should be performed regardless of the position a material resides in the pavement or their perceived layer naming convention, as is the case with basegrade stabilisation that disregards this convention of treating pavement layers separately.

An important acknowledgement from Little's report was that it is unrealistic to be able to develop mix design procedures that cater for all soil types and all binder types, however it is important to have a guiding framework that enables practitioners to follow a structured path that starts with host material characteristics and concludes at selection of a binder type and quantity for project specific validation by further laboratory testing.

A lot of research has continued to result in improvements to stabilisation mix design procedures as was evidenced from work undertaken by the University of California, Davis (Louw, et al., 2016). This particular study focussed on developing mix design methods that would minimise the development of shrinkage cracks in cement stabilised pavement materials. The resulting recommendations were based on numerous trials that examined various delays from the time of cement stabilisation to the time of micro cracking which is reported to be a beneficial method to inhibit the development of shrinkage cracks. The premise to note is that mix design existence and optimisation continue to be studied internationally as the stabilisation industry strives to close the gap on a diminishing array of technical unknowns.

A more recent research report (Opus International Consultants Limited, 2017) provides guidance on selection of binders that are available in New Zealand. The binder selection chart illustrated in Figure 16 demonstrates New Zealand's view that almost any material can be treated with stabilisation technology. Where a host insitu material is considered doubtful, the option to pre-treat the material with lime is a common approach. This is particularly evident for cement and cementitious blends in the first row, which would typically be a desired binder choice when specific strength gains are the objective. A lime pre-treatment in cases where the plasticity index is too high still enables the material to be modified prior to the cementitious treatment. The New Zealand publication however does not provide guidance on the timing between the lime pre-treatment and application of the cementitious binder/s. This form of mix design procedure has been replicated in this research program with one of the three binder types that required a lime pre-treatment.

Characteristic pavement material particle size		Fine grained pavement material > 25% passing 0.425 mm sieve			Coarse grained pavement material <25% passing 0.425mm sieve		
Plasticity index (PI)		PI<=10	10<PI<20	PI>=20	PI<=6	PI<=10	PI>10
Binder type	Cement and cementitious blends*		Lime pre-treatment desirable	Lime pre-treatment essential			Lime pre-treatment desirable
	Lime as hydrated or burnt lime (CaO)	Additional drying action with CaO	Additional drying action with CaO	Additional drying action with CaO	Additional drying action with CaO	Additional drying action with CaO	Additional drying action with CaO
	Hot bitumen						
	Bitumen emulsion**						
	Foamed bitumen**		Lime pre-treatment desirable	Lime pre-treatment essential			Lime pre-treatment
	Granular		Lime pre-treatment desirable	Lime pre-treatment essential		Lime pre-treatment desirable	Lime pre-treatment desirable
	Polymer***						

KEY

- Usually suitable
- Doubtful or supplementary binder required
- Usually not suitable

Notes: * Includes fly ash ** Bitumen emulsion and foamed bitumen can be used with other binders (typically small qualities of cement) *** Includes proprietary polymer materials used as dust suppression and finer soil particle modifier

Figure 16. Preliminary Binder Selection Chart (Opus International Consultants Limited, 2017)

2.6.2 Australia

50 years ago a study into the long term performance of NSW and QLD local government roads strengthened by stabilisation from as early as 1970 was conducted. One of the conclusions from this study was that performance success relied greatly on the contribution of a thorough mix design prior to construction (Hodgkinson, 1996).

The *Road Recycling by Stabilisation* project completed in the early 1990's strongly recommended that material mix designs are carried out to ensure successful performance of stabilisation projects (Ritchie, 1993). This was a critical element of the, '*Checklist for First Project'* that was produced to assist inexperienced engineers when confronted with the task of determining a stabilisation mix design.

In 2001, a survey by Monash University distributed to more than 450 local councils across Australia was undertaken to assess multiple aspects about the use, performance and hindering aspects of pavement stabilisation (ARRB, 2002). Even after earlier publications noted above in the preceding decades emphasized the need to carry out mix designs for proposed stabilisation works, the survey revealed a resounding lack of mix design procedures were readily available for engineers to follow.

Stabilisation mix designs that consist of a host granular material and a chemical binding agent are a relatively common element of the design phase, although the level of evaluation varies amongst pavement engineers, consultants and asset owners from thorough to generic. The most common mix design guidance in Australia which has been published in multiple forms for many decades, is that provided by Austroads in their Guide to Pavement Technology: Part 4D Stabilised Materials, as illustrated in Figure 17.

Particle size	More than 25% passing 75 µm sieve			Less than 25% passing 75 µm sieve		
Plasticity index (PI)	PI ≤ 10	10 < PI < 20	PI ≥ 20	PI ≤ 6 & PI x %passing 75 µm ≤ 60	PI ≤ 10	PI > 10
Binder type						
Cement and cementitious blends(1,3)	Usually suitable	Doubtful	Usually not suitable	Usually suitable	Usually suitable	Usually suitable
Lime	Doubtful	Usually suitable	Usually suitable	Usually not suitable	Doubtful	Usually suitable
Bitumen	Doubtful	Doubtful	Usually not suitable	Usually suitable	Usually suitable	Usually not suitable
Bitumen/ lime blends	Usually suitable	Doubtful	Usually not suitable	Usually suitable	Usually suitable	Doubtful
Granular	Usually suitable	Usually not suitable	Usually not suitable	Usually suitable	Usually suitable	Doubtful
Dry powder polymers	Usually suitable	Usually suitable	Usually unsuitable	Usually suitable	Usually suitable	Usually not suitable
Other proprietary chemical products(2)	Usually not suitable	Usually suitable	Usually suitable	Usually not suitable	Doubtful	Usually suitable

Figure 17. Preliminary Binder Selection Chart (Austroads, 2019a)

This chart relies solely on two properties of the material to be treated, being the particle size distribution and the plasticity index. Once these two properties are known, a binder type, or binder category can be selected.

In the first row, ‘cementitious blends’ is a non definitive binder type and the absence of any further guidance on what type of cementitious binder could be trialled in a laboratory testing program leaves the mix design process confusing for some. Wilmot, (1994) concluded that irrespective of the application there was confusion in the industry around how to select the most appropriate binder type. Further, Wilmot strongly recommended that laboratory testing be undertaken when performing a mix design function so that influencing factors such as climate, soil type, strength requirements and construction programs could be taken into account. It is the author’s opinion that this confusion still remains within the industry today, however generally only with personnel who are not regularly involved in determining stabilisation mix designs and do not have an in depth knowledge of available binders and/or their properties.

AustStab in their *Cement Stabilisation Practice* Technical Note No.5 provide further guidance on the suitability of a host material to perform satisfactorily with cementitious binders based on particle size distribution. This has been reproduced in Table 2.

Table 2. Guide to Property Limits for Effective Cementitious Stabilisation (AustStab, 2012)

Property	**Limit**
Particle Size	
Maximum particle size	75mm
Passing 4.75mm	> 50%
Passing 0.425mm	> 15%
Passing 0.075mm	< 50%
Finer than 0.002mm	< 30%
Plasticity	
Liquid Limit	< 40%
Plastic Limit	< 20%
Plasticity Index	< 20%

Cementitious blends may comprise two or three individual elements, such as GP cement, hydrated lime, slag or flyash. In addition to a variety of binder constituents being available to choose from, the proportions of each constituent are also unknown and often left to the discretion of the mix design manager. There are common blends available that have proven success, such as the 85/15 slag/lime (RTA, 2004) used extensively in the 1990’s by TfNSW (then NSW RTA), 70/30 cement flyash blends used on more than one million square metres of local roads in Brisbane City (Jones, circa 1998) and two different triple blends comprising lime/cement/flyash in the proportions of 30/40/30 and 40/30/30 (AustStab, 2020).

A mix design process for selection of either of these two triple blends is utilised primarily in QLD by TMR, mainly when portions of subgrade are planned to be blended or mixed in with the subbase gravel, or when lower quality subbase gravels are planned to be mixed in with the base gravel. When the plasticity index of the blended material is in the range of 10-20%, their mix design procedure is triggered which is based on the linear shrinkage of the blended materials as show in Table 3.

Table 3. QLD TMR Triple Blend Guide (AustStab, 2020)

	Hydrated Lime	**Cement**	**Flyash**
LS < 6%	30%	40%	30%
LS ≥ 6%	40%	30%	30%

Apart from the specific use of triple blend binders, TMR also have a dedicated Materials Testing Manual that details their preferred mix design procedures to be followed when a stabilisation project is being considered (TMR, 2020c). A series of test methods specific to stabilisation processes is detailed for categories involving cementitious stabilisation, subgrade stabilisation using lime and foamed bitumen stabilisation. This manual is arguably the most advanced mix design procedure of all state road authorities in Australia, however it does not address the process to follow when subgrade materials are mixed into base course gravels. This is because at a state road level where traffic loads and volumes are considerably higher than for local roads, stabilisation of thin pavements that may sit directly on a subgrade layer is generally not carried out (particularly if it is a weak subgrade layer with an insitu CBR less than 3%) and other methods of rehabilitation are often considered (Volker, July, 2019).

Selection or optimisation of the right mix design can clearly be challenging and this is the situation when just granular materials are being evaluated for base course or subbase stabilisation. Furthermore, for basegrade stabilisation projects that comprise various proportions of base layer gravel and subgrade materials, mix design optimisation is theoretically more challenging. This is why mix design protocol is required to assist practitioners in optimising binder types and application rates for use in these circumstances.

2.7 Basegrade Stabilisation

The purpose of this section of the literature review is to reveal evidence of other authorities who have performed, or permit the undertaking of basegrade stabilisation. Conversely where authorities show evidence of forbidding basegrade stabilisation, through actions of knowing prohibition or otherwise, these are also presented. Moreover, examples where other research work has imitated parts of the experimental research being undertaken in this thesis are also presented.

2.7.1 International

There is evidence in the UK that advocates stabilisation of granular pavement materials separately to subgrade materials (Transport Research Laboratory, 1993). When the plasticity index of a material is high enough to cause inefficient mixing of binder into the material, the recommended practice is to initially mix in lime and allow it to ameliorate for 24 hours. Once the plasticity has been reduced to a point that the material is more workable, the cementitious binder is allowed to be mixed in to the modified material. No evidence exists to suggest both material types can be mixed together.

In Malaysia, the federal and state road authority known as JKR (Jabatan Kerja Raya) published a design guide for low volume roads around 8 years ago (JKR Cawangan Kejuruteraan Jalan & Geoteknik, 2012). The guide focusses on provision of structural thickness advice for various flexible pavement types. Base course layers and subgrade layers are dealt with separately in terms of assigned stiffness values. However it is of interest to note that for lightly trafficked stabilised base course materials, the guide references a minimum strength requirement of 0.8MPa UCS and denotes the same requirement for a stabilised subgrade material. Whilst the guide does not expressly describe both layers as a basegrade treatment option, it is implied that if a base course material is mixed with a subgrade material and the resultant blended material UCS can achieve in excess of 0.8MPa, the design requirements are satisfied. It is the author's personal experience from working in Malaysia that this exact situation has occurred and not been met with resistance.

In the United States, the Portland Cement Association (PCA) published research findings that examined the effects of lime and cement stabilisation on medium to high plasticity clay materials (Bhattacharja. & Bhatty., 2003). This concept draws a parallel with the research conducted here, where subgrade soils with medium to high plasticity are being introduced into the base gravel. Three soils were investigated by the PCA that had plasticity index values from 25% to 42%. It was found that higher UCS and CBR strengths were obtained at all ages (up to 100 days) tested with the use of cement over lime.

In the United States, a '*Cementitious Stabilization'* publication was authored by Dallas Little et al for the Transportation Research Board (Little, et al., n.d.). Whilst this document is not anywhere near as detailed or complex as other books and journals published by Little on cement and lime stabilisation topics, this seven page report provides a basic summary of cementitious stabilisation practices in the

US, covering chemistry, binder types, mix design and construction considerations. In consideration of basegrade stabilisation concepts presented in this research, one of the most revealing and important concluding remarks by Little et al occurs in the final section titled, '*Areas for Further Research'* in relation to rehabilitation of existing pavements. It is acknowledged that 'cement-recycled' pavements do and will comprise bituminous wearing courses, base materials and subgrade materials. The recommendation therefore suggests more research is required to obtain better understandings of the performance, design and construction criteria associated with this part of pavement engineering where insitu material variability in pavements can cause outcomes that differ to those predicted at the design stage.

New Zealand's '*Best practice guide for pavement stabilisation'* provides guidance in Table 3.5 on some of the benefits that asset owners, designers and constructors should expect when implementing a stabilisation treatment on new sites and for rehabilitation of existing roads. The table clearly delineates various pavement layers (subgrade, improved subgrade layer, subbase and base) which immediately removes the opportunity to think laterally about the ability to combine any of these layers. Even though the concept of basegrade stabilisation is ultimately to produce a lightly bound base course layer that originally started with a blend of base and subgrade, this delineation and absence of layer blending limits the use of a basegrade stabilisation solution.

2.7.2 Australia

2.7.2.1 National Publications

The Austroads suite of pavement technology guides has a specific part that deals with stabilisation mix design procedures. The current edition is Part 4D: Stabilised Materials (Austroads, 2019a). There have been multiple versions prior to this publication, however edition 1.0 was released in 2006. Prior to 2006, mix design procedures were documented by Austroads in other forms prior to the establishment of the current Pavement Technology series.

In 2002, a working group was formed to develop content for the 2006 edition. A subsequent Austroads report titled, '*Mix Design for Stabilised Pavement Materials*' was published with the recommendations from that working group (Austroads, 2002). Several flowcharts to aid the industry in site investigation and mix design procedures were developed and these supported the working group's recommendations. The site investigation flowchart illustrated in Figure 18 is significant in the context of basegrade stabilisation, or the practice of mixing in subgrade materials into base course granular materials.

Following the highlighted path shown in Figure 18, it is obvious that where a pavement had inadequate existing thickness of granular material, no consideration was given to mixing in the subgrade and effectively insitu stabilisation was suggested to be an unlikely solution. This is an implied inference with the questions asking if other material can be added being related to a granular overlay situation rather than adding subgrade material. Whilst this may be the case for heavily trafficked pavements or where the available thickness of granular base course material is significantly less than the design thickness required, historical and current project evidence in local government lightly trafficked road categories supports the use of basegrade stabilisation.

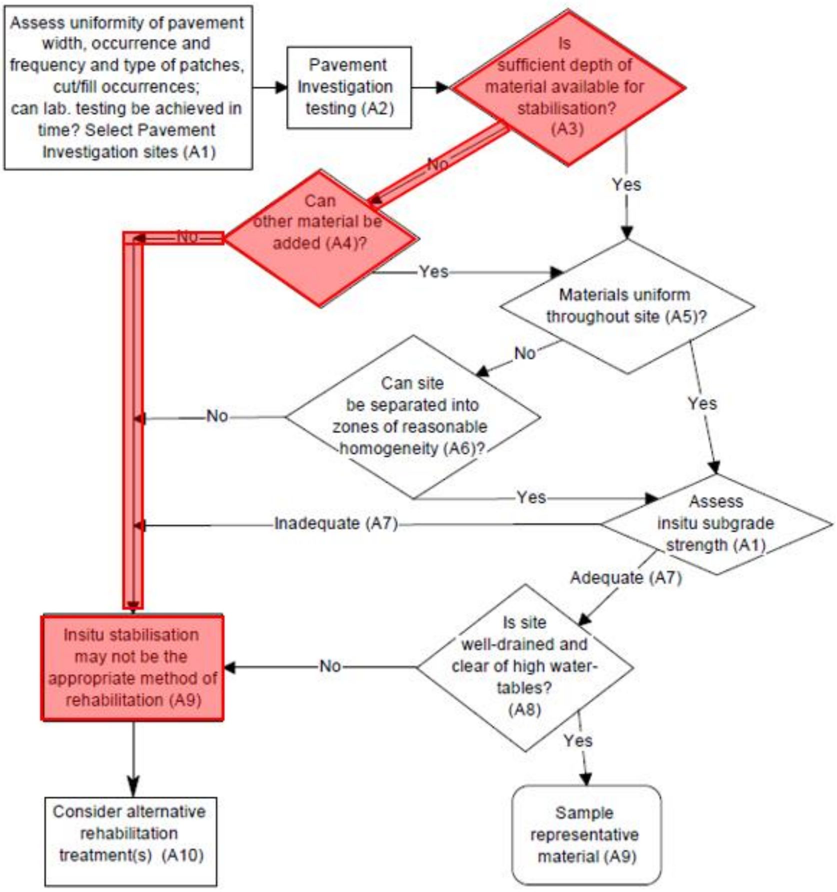


Figure 18. Site Inspection to Assess Stabilisation Suitability (Austroads, 2002)

The AustStab 'Pavement Recycling & Stabilisation Guide' provides comprehensive advice on all aspects of stabilisation technology (AustStab, 2015). Chapter 5 details structural design of stabilised materials. For light trafficked pavements defined as a DESA up to 1.0E+06, AustStab nominate no more than 30% of the subgrade can be incorporated into the pavement layer/s (refer Figure 19). No guidance however is provided on optimisation of mix design protocol when this method is adopted.

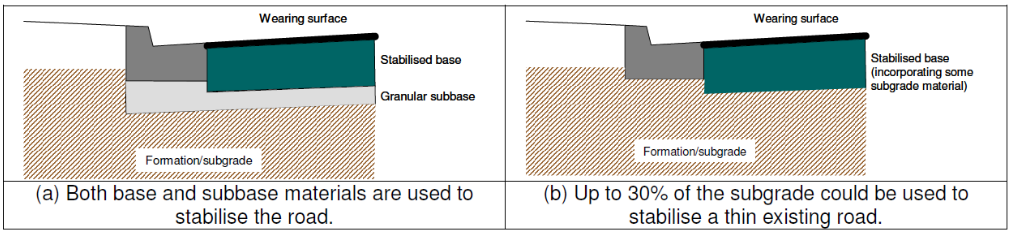


Figure 19. Basegrade Stabilisation Cross Section (AustStab, 2015)

AustStab's technical library contains several other pertinent documents that align to basegrade stabilisation. Their national guideline published to provide guidance on Site Investigations (AustStab, 1999) is aimed at local government roads with low traffic volumes. Material evaluation is a section that describes a basic procedure for dealing with pavements that have thin granular layers and it is expected to incorporate subgrade materials into the pavement. It simply recommends to ensure the material sampling phase reflects the expected stabilisation thickness treatment and subgrade and granular layers are sampled appropriately and replicated in laboratory testing.

AustStab's most recent publication (AustStab, 2020) is aptly titled, '*Triple Blend Stabilisation'*. It provides advice to the stabilisation industry with a focus on selection of an appropriate triple blend binder in base or subbase layers that are mixed with lower quality materials from beneath. Queensland's TMR mix design procedure is referenced which details the use of two triple blends comprising lime/cement/flyash, based on the plasticity index and linear shrinkage of the host material. Other triple blends consisting of slag are also noted, but with no guidance on how to select one. This technical note has been used as the basis for selection of lime/cement/flyash triple blends in this research because it represents current best practice adopted by Queensland's TMR.

Previous references have been made to a Monash University commissioned survey where more than 160 local councils participated (Chakrabarti, et al., 2002). Two of the survey aims were to determine:

- '…*the pavement materials currently used and pavement thicknesses adopted*…'
- '…*the type and quantity (dose rate) of chemical additives used*…'

56% of local road pavements were found to have clayey gravels, while 58-88% of local road pavements were found to have granular thicknesses between 100mm and 200mm sitting directly on the subgrade. 49% of council roads in Queensland were reported to be rehabilitated by reconstruction due to having insufficient depth of suitable pavement materials. The concluding remark in the survey report was that a critical factor for stabilisation not being used in local government authorities was due to the lack of adequate pavement depth. This was an extremely negative outcome for the stabilisation industry who had previous experience with basegrade stabilisation, albeit without any strong evidence of success or robust mix design protocol to enable asset owners to trial the technology.

2.7.2.2 State Government Publications

Implementation of stabilisation treatments on state road networks is used more widely in Queensland than any other state. TMR's Pavement Rehabilitation Manual provides guidance on various forms of stabilisation treatments and also offers limiting factors for inappropriate use (TMR, 2020a). Among the inappropriate uses recommended by TMR, two discount the use of stabilisation when the base gravel is either too thin or where the subgrade is weak and directly supports the overlying granular layer. The manual states;

- *'where the support for the stabilised or modified layer is weak (for example, stabilised base layer lying directly on a weak subgrade)'*
- *'for existing pavements with an inadequate granular/soil thickness for stabilisation…'*

This 'inappropriate use' would likely be mirrored by other state road authorities where traffic loadings are much higher than in local government authorities. Further, the application of basegrade stabilisation is suited to lightly trafficked pavements where lower traffic loads are likely to have less of an effect on pavements supported directly by subgrades, even weak ones.

2.7.2.3 Local Government Publications

There was very little literature able to be sourced from the local government sector that clearly demonstrated a position on the use a basegrade stabilisation concept. The absence of supporting literature by any individual council does not necessarily suggest a rejection of the process, rather a lack of knowledge on the existence of it. This lack of direction reinforces why mix design guidance is required to assist those local councils who may in the future consider adopting a basegrade stabilisation approach as part of their network rehabilitation strategy.

A study tour granted to a Tasmanian based construction engineer in the late 1980's enabled review of stabilisation practices from Sydney and Brisbane councils who established widespread use with the technology. One of the findings from the study tour was that stabilised pavements treated with cementitious binders are somewhat 'forgiving' whereby up to 25% of the subgrade (usually clay) could be incorporated into the base with no significant detrimental effects (Petrusma, 1988). Where more than 25% of the proposed pavement to be stabilised was a clay subgrade, there was no inhibition to pre-treating the pavement with lime prior to stabilising with cement. Two Sydney Councils, Blacktown and Bankstown, reported 70% and 60% respectively of the layer to be stabilised should be granular.

The Cement & Concrete Association (CCA) commissioned an investigation in the mid 1990's into the performance of local government roads in councils from Queensland, New South Wales, Victoria and South Australia up to the period 1975 from (Hodgkinson, 1996). Apart from a strong recommendation to support the use of insitu stabilisation as an economical rehabilitation method (35-50% savings) and a 75% longevity probability, one of the key findings relevant to this research was related to material characteristics. Successful performance was deemed to be likely when at least 80% of material in the travelling lanes (at least 60% in shoulders) to be stabilised is granular material. Material properties should include a maximum plasticity index of 20%, a maximum of 50% material passing the 0.425mm sieve and 40mm maximum aggregate size. This conclusion supports the incorporation of subgrade materials into granular pavement layers, albeit with no further guidance on what constitutes complying subgrade material properties or thickness to be blended into the base.

Another investigation into the performance of local council roads rehabilitated by insitu stabilisation was conducted in the early 1990's by Ritchie (1993). Three western Sydney councils in New South Wales were the focus of Ritchie's investigation, being Holroyd, Bankstown and Blacktown. Ritchie was the Assistant Director of Operations at Holroyd City Council at the time of the study. Notable findings on performance of roads stabilised between 1968 and 1993 were up to 50% reductions in 85% of maximum deflections and sound performance after 15 years of service.

The roads investigated by Ritchie were typical light traffic residential roads with 20 year design lives of 1.0E+04 to 1.0E+05 ESA's. The common stabilisation treatment used a mix design with 4% cement by volume. The thickness of existing granular layers on top of subgrades with insitu CBR's between 3% and 5% ranged from 125mm to 175mm. The standard design thickness was 150mm in the majority of cases. It is highly likely that whether intended or not, these standard treatments would have encroached into the subgrade and brought it into the pavement during the mixing processes onsite. This was confirmed by a contractor who was involved in delivering much of these projects (Wilmot, 2020).

Brisbane City Council (BCC) would arguably be among the largest users of stabilisation for pavement rehabilitation treatments in Australia, however the majority of their experiences occurred in the 1980's and 1990's. The late Errol Jones was a pioneer of stabilisation treatments at Brisbane and instigated much of what is now considered a legacy within the local stabilisation community. After almost two decades of substantial pavement recycling, Jones conducted an internal investigation to review the performance of their stabilised road network (Jones, circa 1998). Among the multiple recommendations made by Jones including source rock for base course materials, wearing course thicknesses, subgrade strength and application of various traffic loadings to various road classifications, one important recommendation was the ability of the subgrade to be incorporated into the base gravel. This was on the condition that the properties of the combined blend were deemed suitable, being a function of the plasticity index (< 30%) and <25% passing the 0.075mm sieve. Where these parameters were not met, Jones recommended lime be considered as part of the blend, but no guidance was provided on the amount of lime within the blend.

The latest version of Brisbane City's pavement rehabilitation manual (2011) contains a flowchart shown in Figure 20 to assist users in the identification of suitable project sites to be stabilisation candidates.

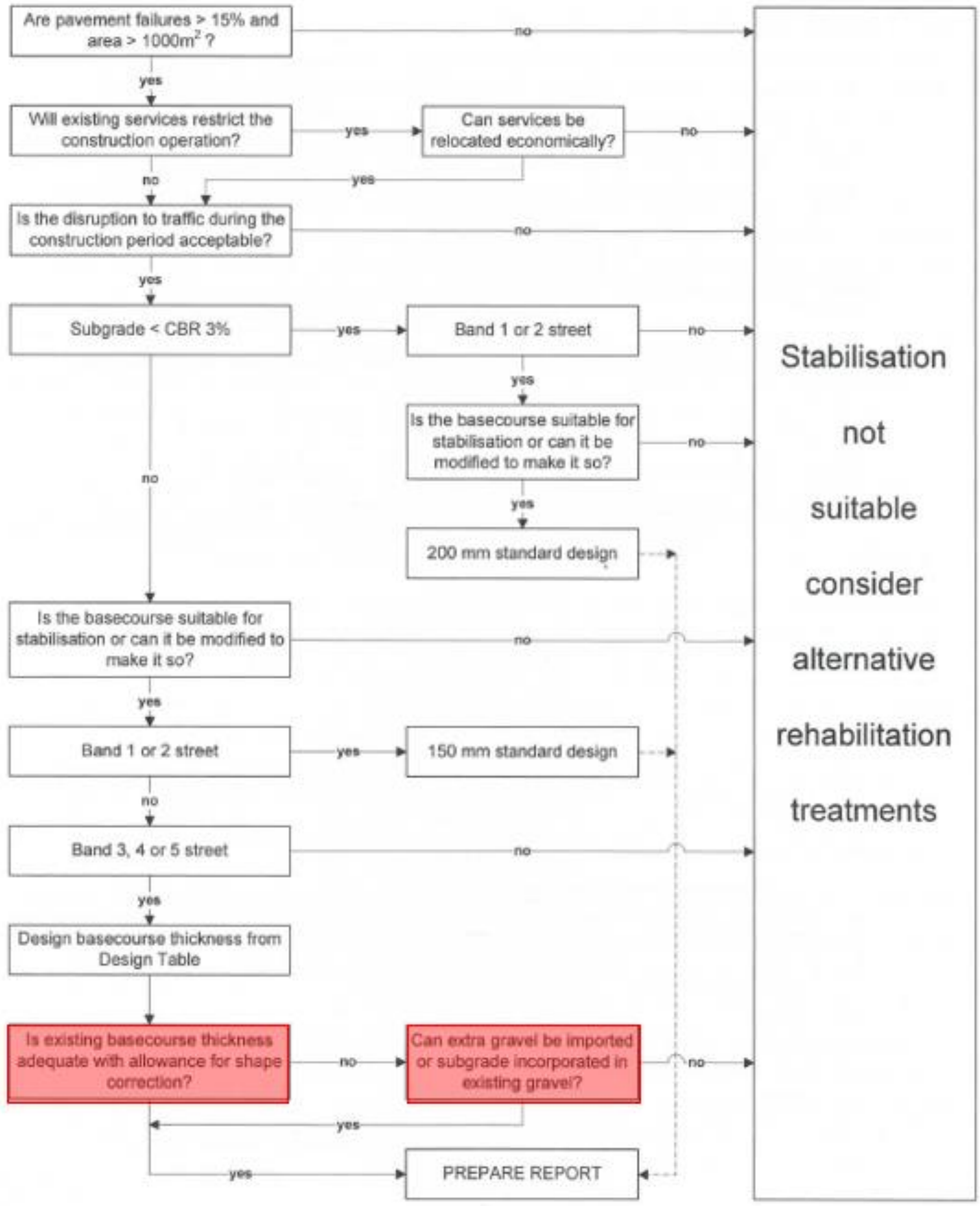


Figure 20. Stabilisation Suitability Assessment Flowchart (Brisbane City Council, 2011)

Following the highlighted path in Figure 20, it is evident that BCC theoretically allow subgrade materials to be mixed into the pavement layers if the existing basecourse thickness is deemed to be inadequate. However it is unclear what the mix design process would be if this was the case, based on the variability of subgrade material properties and the quantum of subgrade to be incorporated into the base. Even though the advice from the above flowchart provides a positive enabling outcome for pavement engineers to utilise basegrade stabilisation, BCC currently does not promote nor agree with this practice for fear of poor performance due to the perception of negative influence from the subgrade when placed under load during construction (Schramm, 2020).

2.8 Literature Overview

In broad terms, insitu stabilisation of lightly trafficked pavements has been implemented successfully in Australia on the local government road network since the middle of the last century. In particular, this success has largely been observed in the rehabilitation of base course materials and to a lesser extent, improvement of subgrade materials (ie. reductions in plasticity index and moisture susceptibility, increases in CBR).

Basegrade stabilisation is not a new concept and has also been used widely in Australia, mostly in the local government road network where thin pavements overlying subgrade materials exist and were treated simultaneously through insitu stabilisation. However there is a considerable lack of literature available to support the mix design process for a basegrade stabilisation approach. In contrast, there are multiple references from international and Australian literature acknowledging the notion of incorporating subgrade materials into base course quality materials during construction operations.

Despite this notion, for basegrade stabilisation to become a more widely recognised and standard practice in Australian local councils, it is clear that there needs to be some established protocol to guide practitioners into the field of stabilisation mix designs. This is because there is no evidence available to the author to suggest any such mix design procedures currently exist to optimise a mix design for basegrade stabilisation solutions.

3. CASE STUDIES

Although basegrade stabilisation as evidenced in the literature review has been carried out by various local councils, no published evidence was able to be sourced to illustrate specific project examples. Three local councils who have adopted what is now termed basegrade stabilisation in the last 3 years as a strategic approach to solving their network challenges of thin existing pavements are presented. Structural thickness design and mix design protocol is revealed for each case study. The councils are from Queensland, New South Wales and Tasmania. It is likely that many other Councils are practising basegrade stabilisation techniques, however these three are known to the author.

3.1 Sunshine Coast Council (QLD)

St James Court, Little Mountain is located within the municipality of Sunshine Coast Council. It is west of the coastal town of Caloundra and approximately 90km north of Brisbane. This site has been advertised on a public tender for pavement rehabilitation (Sunshine Coast Council, 2020). St James Court is a local access residential road as shown in Figure 21 and Figure 22. The limit of work shown on the right side of Figure 21 (shaded) comprises a length of approximately 200m and a total area of 935m^2. At the time of writing, the construction works had not commenced.

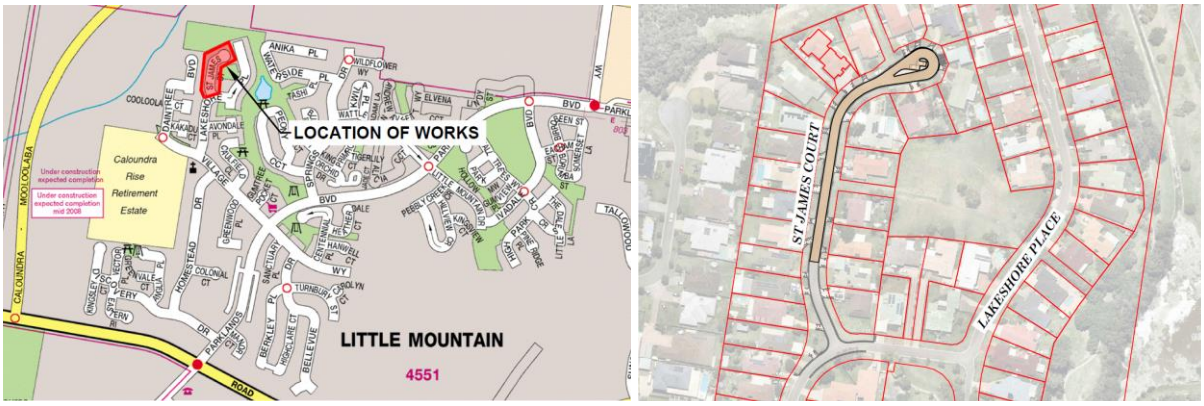


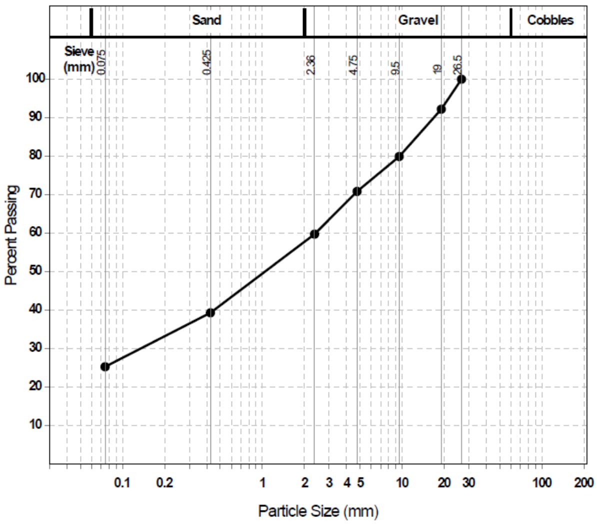
Figure 21. St James Court Locality & Limit of Work (Sunshine Coast Council, 2020)

Figure 22. Street View of St James Court (ref: Google Maps)

A geotechnical investigation was undertaken by the Council using their internal resources. Material samples were delivered to a specialist material sampling and testing organisation (Douglas Partners) who completed a suite of laboratory tests. Depicted in Figure 23, the existing pavement was a silty sandy gravel that was approximately 200mm thick sitting directly on a clay subgrade.

Figure 23. St James Court Test Trench (Sunshine Coast Council, 2020)

The laboratory testing initially included host material characterisation. Subgrade soaked CBR tests resulted in the council adopting a design subgrade CBR of 1.5%. Subgrade samples tested produced CBRs ranging from 1.5% to 6% and swell characteristics ranging from 0.0% to 4.0%, the latter being classified as highly expansive (Austroads, 2017). This low design CBR ultimately dictated the structural rehabilitation thickness which was determined to be 300mm. Properties of the basegrade pavement comprising 200mm of gravel and 100mm of subgrade are illustrated in Figure 24.



Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)	
Liquid Limit (%)	38.6
Plastic Limit (%)	18.4
Plasticity Index (%)	**20.2**

Linear Shrinkage (Q106)	
Shrinkage Drying Type	Oven Dried
Linear Shrinkage (%)	8.8

Figure 24. St James Court Basegrade Material Properties (Sunshine Coast Council, 2020)

The second phase of laboratory testing was to conduct UCS tests of the blended base and subgrade in the proportions of 75/25. Although the data above suggests a ratio of 67/33 based on thickness proportions of 200mm base/100mm subgrade, that data was not representative of the entire site. Due to the high proportion of clay subgrade being incorporated and the low quality of the subgrade, the council decided to model a pre-treatment of the pavement with 3% hydrated lime and allow it to ameliorate for 24 hours. Cement/flyash blends were then added at three different application rates by dry mass. The UCS results are shown in Table 4.

Table 4. St James Court Mix Design Results (Sunshine Coast Council, 2020)

	Sample 1	Sample 2	Sample 3
Hydrated Lime	3%		
Amelioration Period	24 hours		
70/30 Cement/Flyash	3%	4%	5%
UCS (MPa)	1.5	1.6	1.8

The UCS samples were cured for 7 days at ambient temperature conditions (23ºC) which suggests that field strengths could obtain higher values over longer periods of time. Samples exposed to 7 day curing conditions with fast setting binders generally do not achieve the equivalent 28 day cured strengths (Wilmot, 1994).

The pavement design drawing released in the public tender documents is reproduced in Figure 25. It describes the required stabilisation treatment in the blue shaded area.

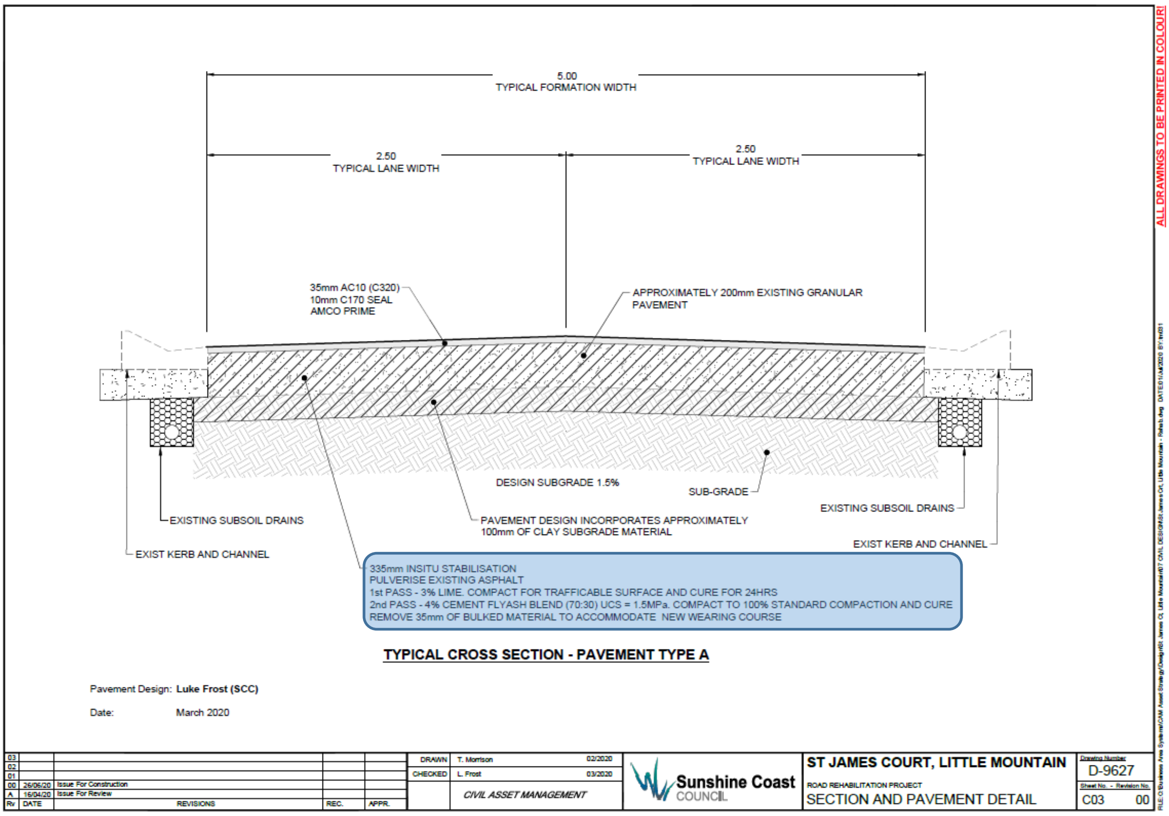


Figure 25. St James Court Pavement Design (Sunshine Coast Council, 2020)

The resulting design adopted was a 300mm insitu stabilisation treatment with an initial 3% hydrated lime. After 24 hours of curing (amelioration), the site was specified to be stabilised again with 4% of a 70/30 cement/flyash general blend. At the completion of both days' work, 35mm of bulked material caused by an increase in volume from the additional mass incorporated into the pavement is to be removed. This is to accommodate the final bituminous spray seal interlayer and AC10 asphalt wearing course.

3.1.1 Summary

This lightly trafficked residential access road was deemed to have insufficient existing granular material to satisfy the thickness required for Council's rehabilitation design parameters. The solution adopted involved a design to incorporate one third of the clay subgrade with a design CBR of 1.5%. In order for the clay subgrade to be adequately altered and permit satisfactory chemical reactions with a cementitious binder, an initial treatment using 3% hydrated lime was designed. After 24 hours of amelioration, a 70/30 cement/flyash blend was specified to be mixed into the modified pavement to achieve the laboratory obtained 1.6MPa.

The absence of a mix design procedure based on host material characteristics of the base and subgrade may not have allowed the council to establish an optimum mix design.

3.2 Port Macquarie Hastings Council (NSW)

The municipality of Port Macquarie Hastings Council (PMHC) is located approximately 380km north of Sydney, New South Wales. The local council has adopted basegrade stabilisation methods to numerous roads in urban areas in the past 3-4 years. It is understood that one of the primary drivers for their decision to take this approach was due to inadequate existing pavement thickness and the desire to reduce the cost of conventional 'remove and replace' rehabilitation treatments (Larkan, 2020).

Solutions incorporating basegrade stabilisation have evolved over time through trial and error due to a lack of published guidance on mix design procedures. It has been at the discretion of the council engineers combined with the experience of the stabilisation contractor who eventually arrived at a standard mix design of 5% 60/40 slag/lime. It is understood that the application rate sometimes varied based on observations of bore log data (granular thickness v subgrade thickness) and material descriptions, but the binder type remained unchanged (Larkan, 2020).

An example of some initial projects trialled by Port Macquarie Hastings Council using basegrade stabilisation were taken from their 2017/18 capital works program. Ten urban sites in the town of Wauchope located approximately 20km west of Port Macquarie were identified as candidates for basegrade stabilisation and subsequently rehabilitated using that method. The locations of these sites are illustrated in Figure 26. Each site was insitu stabilised to a depth of 350mm. The target UCS for each project was 1.5MPa after 7 days accelerated curing. Note that NSW is the only state in Australia that regularly practices accelerated curing UCS testing due to their use of slow setting binders that incorporate higher portions of slag, lime and flyash.

Figure 26. Urban Basegrade Sites in Wauchope from 2017/18 Capital Works Program, NSW

Figure 27 shows the difference between a typical candidate site targeted for basegrade stabilisation (Bain St) and the condition of a completed basegrade stabilised site (Campbell St).

Figure 27. PMHC Basegrade Stabilisation Sites: Bain St (L), Campbell St (R) (Larkan, 2020)

A summary of the pavement investigation bore log data, traffic and design information from two of the sites which were considered representative of the other sites are detailed in Table 5 (Larkan, 2020). Rationale for selection of the 350mm treatment thickness has not been investigated.

Table 5. Materials Profile and Design Data (Larkan, 2020)

Road	Design Life	Design Traffic (DESA)	Base Material		Subgrade	
Mackay St	20 years	4.00E+04	Silty Clayey GRAVEL	200mm	Silty CLAY	CBR8
Graham St		8.00E+05	Silty GRAVEL	100-200mm	Silty Gravelly CLAY	CBR12

Unfortunately no performance data or test results were able to be produced by the Council. However post construction test reports were provided for several basegrade stabilisation projects performed in their 2018/19 capital works program (Larkan, 2020). These are shown in Table 6.

Table 6. Post Construction Test Results - FY19 Capital Works Program, Wauchope (Larkan, 2020)

Road	Location	Binder Type	Binder %	Average UCS (MPa)
Colonial Circuit	Ch48.05	60/40 Slag/Lime	5	2.6
	Ch115.25			2.6
Fairmont Drive	Ch42.76			1.5
Cogo Close	Ch15.87			1.3
Sarahs Crescent	Ch45.15		2	0.6
	Ch65.00			0.6
	Ch115.15			1.7
	Ch193.00			3.4

Whilst the results from Colonial Cir, Fairmont Dr and Cogo Cl are all relatively consistent, it is not 100% clear what influenced the fluctuation in results in Sarahs Cres. One of the likely causes is due to the numerous quantity of heavy patches in the existing pavement and because the stabilisation depth was only 200mm (Larkan, 2020). It is hypothesized that by following a mix design procedure to assist with selection of a different binder type and/or a justified application rate, more consistent strengths may have been obtained. It is also worthwhile noting that the Council remained positive about the strengths achieved, given the variability of the original pavement materials and the significantly reduced capital cost required to undertake basegrade stabilisation in lieu of a reconstruction method (Larkan, 2020).

3.2.1 Summary

Port Macquarie Hastings Council have been undertaking basegrade stabilisation since the 2017/18 financial year (Larkan, 2020). They have trailed this method in urban residential access roads where the existing base gravel thickness was deemed too thin to stabilise. In lieu of reconstructing these lightly trafficked roads, brave engineering decisions were made to incorporate the subgrade into the base gravels. Although some variability in post construction UCS results have been observed, the asset renewal strategy is showing visual signs of positive performance.

3.3 Derwent Valley Council (TAS)

Three sites were identified by Derwent Valley Council in Tasmania as being in need of rehabilitation. The sites were awarded for construction in early 2020. The sites known as Shoobridge Place, Downie Circle and Matheson Court are illustrated together in Figure 28. All are lightly trafficked residential cul-de-sac streets.

Figure 28. Basegrade Stabilisation Sites in Tasmania (Google, 2020)

The original condition of each site prior to rehabilitation by basegrade stabilisation is shown in Figure 29.

A basegrade stabilisation design was adopted for all three sites, with a target UCS of 1.5MPa (S.P.A., 2020). The Council has allowed access to the pavement design report that was used for these projects. All information provided herein has been extracted from that report (S.P.A., 2020). Each site had a thin existing pavement profile sitting directly on the subgrade.

Figure 29. Basegrade Stabilisation Sites (Google, 2020)

Two test pits were excavated at each location and material samples taken to a NATA certified laboratory for classification testing and subsequent trial mix design (UCS) testing. Due to the existing pavement thickness of each site ranging from 190-220mm (average) and 180mm (minimum) to 290mm (maximum), various mix designs were trialled. These are shown in Table 7.

Table 7. Mix Design Trials (S.P.A., 2020)

Location	Test Pit No.	Base Depth (mm)	Average Depth (mm)	Presumptive DESA	Design Thickness (mm)	Day 1 Treatment	Day 2 Treatment	Mix Design (7 day UCS)	Sample Blend
Matheson Place	TP1	200	190	< 10E4	200	300mm Lime	200mm GP	3% lime Day 1	60% Base
Matheson Place	TP2	180						2% & 3% GP Day 2	40% Subgrade
Downie Circle	TP1	200	200	< 10E4	200	300mm Lime	200mm GP	3% lime Day 1	65% Base
Downie Circle	TP2	200						2% & 3% GP Day 2	35% Subgrade
Shoobridge	TP1	290	220	< 10E4	200	200mm GP	N/A	2% & 3% GP	75% Base
Shoobridge	TP2	150							25% Subgrade

Results of the above trials are shown below. All UCS tests were cured for 7 days at ambient temperature and tested in accordance with AS5101.4. As for the Sunshine Coast Council case study, it is likely that strengths achieved with cement after 28 days curing would be higher than those shown in Table 8. The initial 3% lime treatment was applied 24 hours prior to the introduction of the cement.

Table 8. Trial Mix Design UCS Results (S.P.A., 2020)

	UCS (MPa)		
	Matheson Ct	**Downie Cir**	**Shoobridge Pl**
3% Lime / 2% Cement	0.7	1.2	-
3% Lime / 3% Cement	0.8	1.3	-
2% Cement	-	-	0.2
3% Cement	-	-	0.7

Based on the results obtained, a decision was made to increase the thickness of the second day cement treatment for Matheson Court in lieu of the strengths being below 1MPa. The Downie Circle design remained as per the trial. The initial concept for Shoobridge Place was to attempt to achieve the design strength without a lime pre-treatment, as only 25% of the subgrade was being incorporated into the base gravel compared to 35-40% at the other two sites. However this trial did not yield conforming strengths. This is why the final design adopted for Shoobridge Place included a pre-treatment with lime. The mix designs adopted for field implementation are displayed in Table 9, along with some construction images from Shoobridge Place in Figure 30.

Table 9. Construction Mix Designs (S.P.A., 2020)

	Field Target Design Spread Rate		
	Matheson Ct	**Downie Cir**	**Shoobridge Pl**
3% Lime (Day 1)	300mm, 18kg/m2	300mm, 19kg/m2	300mm, 19kg/m2
3% Cement (Day 2)	250mm, 15kg/m2	200mm, 12.5kg/m2	250mm, 16kg/m2

Figure 30. Basegrade Stabilisation, Schoobridge Place, New Norfolk, TAS (Goodsell, 2020)
3% Lime Treatment (L); 24 Hour Curing Period (Middle); 3% Cement Treatment (R)

3.3.1 Summary

Derwent Valley Council is one of the first local government organisations in Tasmania to deliberately trial the process of basegrade stabilisation. The sites chosen were of low risk, given their location, light traffic loads and relatively small size. A reasonably thorough mix design program was undertaken which resulted in a mix design comprising an initial lime treatment followed by a cement treatment after the pavement ameliorated for 24 hours. The ability to achieve the design strength of 1.5MPa was enabled by the project specific mix design trials, albeit in the absence of any published guidelines on optimisation of the mix design outcome. Regardless of the positive approach taken with these sites, the absence of a mix design procedure underpinned by evaluation of untreated material properties may not have resulted in optimised mix designs.

4. RESEARCH METHODOLOGY

The research methodology was founded on quantitative methods where a series of laboratory experiments were conducted on various materials. The results enabled recommendations to be made on a proposed mix design procedure that aligned with the research question of how to optimise the mix design process for basegrade stabilisation.

The research methodology included the following sub sections:

- Research Scope
- Selection of the raw pavement materials used in the laboratory testing
- Selection of the stabilising binders used in the laboratory testing
- Laboratory testing program
- Laboratory test methods
- Data Analysis
- Results Hypothesis

All photographs shown in this section were taken by the author.

4.1 Research Scope

One base gravel and three subgrade materials formed the generation of nine 'basegrade' pavement materials. These have each been identified as Pavement Type 1, Pavement Type 2…Pavement Type 9. Throughout the research reporting, they have also be recorded with the Pavement Type acronym, PT. Hence they have been reported as PT1, PT2…PT9.

Three different subgrade proportions have been adopted for blending into the base gravel, to represent the percentage of subgrade that would be mixed into a base gravel. These have been applied at 20%, 35% and 50%. This resulted in the nine basegrade pavements based on three subgrade materials and three subgrade proportions. This is illustrated in Table 10.

Table 10. Pavement Type Configurations

Pavement Material	Type 2.3 Gravel								
Subgrade Material	Pittsworth Alluvial			Redlands Silt			Wallum Court Clay		
Gravel / Subgrade Proportions (%)	80/20	65/35	50/50	80/20	65/35	50/50	80/20	65/35	50/50
Pavement Type ID	**PT1**	**PT2**	**PT3**	**PT4**	**PT5**	**PT6**	**PT7**	**PT8**	**PT9**

All nine pavement types have been subjected to a variety of laboratory tests detailed in Section 4.4 Laboratory Testing Program. Tables 11 and 12 illustrate a summary of the testing phase matrix for the untreated and treated materials respectively.

It was anticipated that these pavement types would yield properties (ie. Atterberg Limits and particle size distribution) that do not meet the requirements of the current Austroads mix design binder selection chart shown in Figure 17 for use with cementitious blends.

Table 11. Research Test Matrix 01 – Untreated Materials

UNTREATED MATERIALS					
Phase 1 Testing	**Phase 1 Tests**	**Phase 2 Testing**			**Phase 2 Tests**
Raw Materials	PSD, Atterbergs, MDR, CBR	**Pavement Type**	**Base 1**	**Subgrade 1**	PSD, Atterbergs, MDR, CBR on all Pavement Types
Type 2.3 Gravel		PT1	80%	20%	
		PT2	65%	35%	
		PT3	50%	50%	
Pittsworth Alluvial		**Pavement Type**	**Base 1**	**Subgrade 2**	
		PT4	80%	20%	
		PT5	65%	35%	
Redlands Silt		PT6	50%	50%	
		Pavement Type	**Base 1**	**Subgrade 3**	
Wallum Court Clay		PT7	80%	20%	
		PT8	65%	35%	
		PT9	50%	50%	

Table 12. Research Test Matrix 02 – Treated Materials

	TREATED MATERIALS									
	Phase 3a Testing			**Phase 3b Testing**		**Phase 3 Tests**	**Phase 4 Testing**			**Phase 4 Tests**
	Lime/Cement/Flyash Triple Blend			**60/40 Slag/Lime**		UCS on all samples MDR Atterbergs on Pavement Types PT2, PT5, PT8 (65/35 blend)	**Day 1: Lime** **Day 2: 70/30 GB Cement**			UCS on all samples MDR Atterbergs on Pavement Types PT2, PT5, PT8 (65/35 blend)
Pavement Type	**3%**	**5%**	**7%**	**5%**	**7%**					
PT1	30/40/30	30/40/30	30/40/30	60/40	60/40		3% lime/ 2% GB	3% lime/ 3% GB	3% lime/ 4% GB	
PT2	40/40/20	40/40/20	40/40/20							
PT3	50/30/20	50/30/20	50/30/20							
Pavement Type	**Lime/Cement/Flyash Triple Blend**			**60/40 Slag/Lime**			**Day 1 Lime / Day 2 Cement**			
PT4	30/40/30	30/40/30	30/40/30	60/40	60/40		3% lime/ 2% GB	3% lime/ 3% GB	3% lime/ 4% GB	
PT5	40/40/20	40/40/20	40/40/20							
PT6	50/30/20	50/30/20	50/30/20							
Pavement Type	**Lime/Cement/Flyash Triple Blend**			**60/40 Slag/Lime**			**Day 1 Lime / Day 2 Cement**			
PT7	30/40/30	30/40/30	30/40/30	60/40	60/40		3% lime/ 2% GB	3% lime/ 3% GB	3% lime/ 4% GB	
PT8	40/40/20	40/40/20	40/40/20							
PT9	50/30/20	50/30/20	50/30/20							
	1 Day Process						**2 Day Process**			

The initial task was to select a single source base gravel and three subgrade materials that were representative of those found in local government jurisdictions around Australia. The source of the four materials was from south east Queensland and northern New South Wales, commensurate with the physical location of the author and the testing laboratory.

The majority of existing granular materials encountered in local government roads which are in need of rehabilitation have often degraded over time due to traffic loading, moisture effects, particle breakdown, etc. and generally do not reflect the properties of a new quarried base material (eg. a fine crushed rock). The base gravel selected was therefore a 'Type 2.3' standard unbound granular material (TMR, 2020b) as categorised by the Queensland Department of Transport and Main Roads (TMR) for use as subbase materials (TMR, 2020b), rather than a Type 2.1 or Type 2.2 unbound material which are designed for use as high quality base layers. The reason for selecting a quarried product rather than an existing base course gravel from a physical road pavement, was due to the repeatability of the product and known properties listed in the specification (TMR, 2020b).

The subgrade samples selected were fine grained soils represented by clays and silts that have a wide range of consistency limits, ie. plasticity index and liquid limit.

All material samples were sent to the Border-Tek Pty Ltd laboratory for testing in Tweed Heads (northern New South Wales) that is accredited by the National Association of Testing Authorities (NATA). Testing of the raw materials (untreated) was limited to:

- moisture-density relationships (MDR)
- Atterberg limits
- particle size distribution (PSD)
- California Bearing Ratio (CBR)

Testing of the nine pavement types mixed with various stabilising binders was limited to testing of:

- moisture-density relationships (MDR)
- Atterberg limits
- Unconfined compressive strength (UCS), cured for 28 days

The results were subsequently analysed and compared against the target UCS range of 1-2MPa which is the recommended strength range for basegrade stabilisation. This recommendation is based on the findings of the literature review and current practices in local government where lightly trafficked pavements are insitu stabilised as a form of long term rehabilitation. Other correlations with host material properties were also examined.

4.2 Selection of Raw Pavement Materials

Each of the four material types were assigned a unique identifying number that was used throughout the research testing and subsequent reporting as detailed in Table 13.

Table 13. Raw Material Identification Numbers

Raw Material Description	Raw Material ID #
Type 2.3 Gravel	1
Pittsworth Alluvial	2
Redlands Silt	3
Wallum Court Clay	4

Selection of each subgrade source was intended to provide distinct variations in properties, particularly the consistency limits. The raw materials are illustrated in Figure 31.

Figure 31. Raw Materials

The geographical location of the source of the four raw materials is illustrated approximately on the map in Figure 32. All raw materials were sourced from south east Queensland and northern New South Wales, due to the proximity of the testing laboratory and the author.

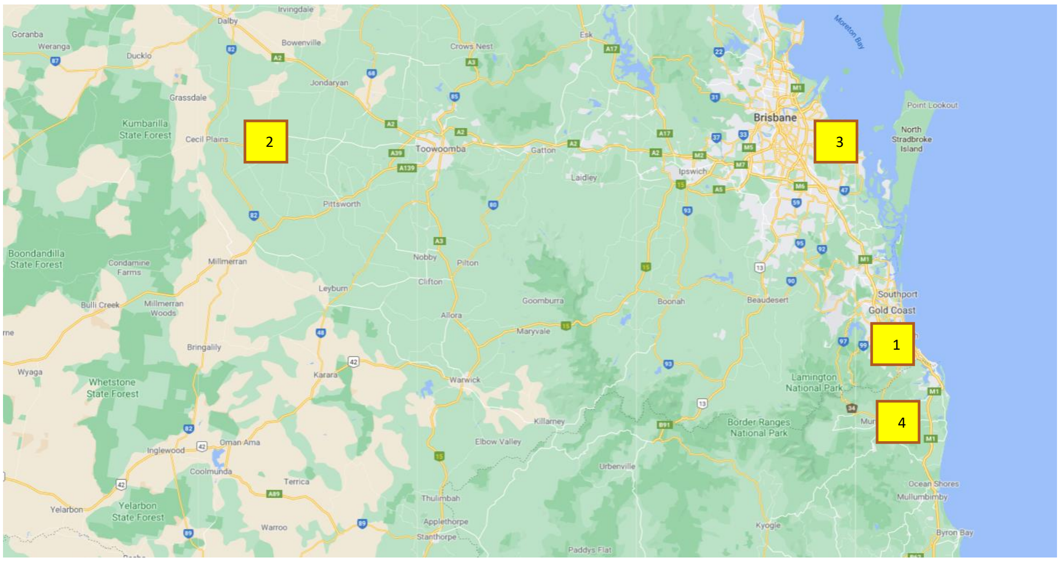


Figure 32. Raw Material Source Locations (Google, 2020)

Further details of the source and description of each material is provided in the following sub sections.

4.2.1 Raw Material 1

The source of the base gravel material was from a Boral quarry located at West Burleigh, QLD (City of Gold Coast). It is a subbase quality material compliant with the TMR specification MRTS05 Unbound Pavements (TMR, 2020b). Approximately 200kg of material was collected for testing with a sample shown in Figure 33.

Figure 33. Type 2.3 Gravel

4.2.2 Raw Material 2

The first subgrade raw material sourced was provided by Toowoomba Regional Council from a site where they were intending on undertaking a pavement rehabilitation project due to the significant defects in the pavement caused by the weak expansive subgrade. The source of the Pittsworth Alluvial was from Bongeen Road, Bongeen, QLD, located approximately 50km west of the city of Toowoomba. Bongeen is nearby the town of Pittsworth.

The subgrade material was collected during a material sampling exercise being carried out by the local Council (refer Figure 34). The material samples were collected by the author during the excavation work and transported to the testing laboratory. Approximately 250kg of material was collected for testing.

Figure 34. Source of Pittsworth Alluvial, Bongeen Rd

4.2.3 Raw Material 3

The second subgrade material was sourced from a residential development located on Collingwood Road, Birkdale, QLD (Redland City Council). This was a small development with the earthworks being carried out by Shadforth Civil (refer Figure 35). The natural subgrade was a collected by a representative from the testing laboratory. Approximately 250kg of material was collected for testing with a sample shown in Figure 35.

Figure 35. Source of Redlands Silt, Collingwood Rd

4.2.4 Raw Material 4

The final subgrade material was sourced and collected by a representative from the testing laboratory from Wallum Court, Clothiers Creek, NSW (Tweed Shire Council). This is an access road leading to an existing quarry site (refer Figure 36) that is known for its low plasticity clays based on previous material tests conducted on the material (Dick, 2020). Approximately 250kg of material was collected for testing with a sample shown in Figure 36.

Figure 36. Source of Wallum Court Clay, Wallum Court (left image ref: Google, 2020)

4.3 Selection of Stabilising Binders

All of the binding agents were supplied by Wagners from their Toowoomba facility in south east Queensland. The four individual constituents were General Purpose Cement (GP), hydrated lime, flyash and ground granulated blast furnace slag (GGBFS). 20kg of each product was supplied (shown in Figure 37) and delivered to the testing laboratory.

Figure 37. 20kg Binder Samples

Based on the specification requirements in Australia for the manufacture and supply of binders (Austroads, 2019a), the properties of each individual binder sourced for this research were expected to be representative of all individual binder constituents that are commercially available to the Australian stabilisation market by other registered suppliers. This is due to the compliance of each binder type that was verified and summarised in the tables below.

Laboratory mix design testing for any stabilisation project is generally always preferred to be undertaken with binder samples form the supplier proposed to be used for delivery of product for the project. No evidence was found to support that any significant variations in strength testing results would occur from using different binder suppliers. The key was to ensure that each supplier manufactured, stored and transported their products in accordance with relevant specifications.

Some of the binder requirements established by the respective standards described in Section 2.5 and the test results for each of the binders used in this research are displayed in Table 14 through 17. Compliance test reports for each of the individual binders are contained in Appendix A.

Table 14. Binder Compliance Results: GP Cement (Wagners, 2020)

Initial Setting (minutes)		**Final Setting (minutes)**		**Loss on Ignition (%)**	
Minimum	Test Result	Maximum	Test Result	Limit	Test Result
45	135	360	210	None	1.5

Table 15. Binder Compliance Results: Hydrated Lime (Wagners, 2020)

Available Lime (%)		Silicon Dioxide Content (%)		Loss on Ignition (%)	
Minimum	Test Result	Maximum	Test Result	Maximum	Test Result
85*	93.4	2	1.3	27	24.8

* Limit may vary between states

Table 16. Binder Compliance Results: Flyash (Wagners, 2020)

Strength Index (%)		Moisture (%)		Chemical Composition (%)	
Minimum	Test Result	Maximum	Test Result	Minimum	Test Result
75	93	0.5	< 0.1	70	94.8

Table 17. Binder Compliance Results: Slag (Wagners, 2020)

Fineness Index (m^2/kg)		Magnesium Oxide (%)		Loss on Ignition (%)	
Limit	Test Result	Maximum	Test Result	Limit	Test Result
None	465	15	6	None	0.2

Each of these binders were combined in various blends to form three distinct testing phases of the research. Prior to the binders being added to the nine pavement types, the individual binders were manually combined in their dry state based on the proportion of each constituent (ie. 60% lime and 40% slag). Addition of the binder blends to each of the pavement types was undertaken in accordance with Q135A test method (TMR, 2020c). Details of these blends are described further in Section 4.4.3.

4.4 Laboratory Testing Program

A comprehensive testing program was developed with multiple dependent and independent variables. The primary dependent variable in this research was the evaluation of the strength of the cured samples measured by UCS. The target strength gain for lightly bound materials was 1-2MPa (Austroads, 2019a) after 28 days ambient temperature curing and 100% standard compaction of samples (TMR, 2020c). The testing program was managed through four separate phases.

4.4.1 Testing Phase 1: Raw Materials

Material characteristic testing was initially performed on the four raw materials by Border-Tek to establish the characteristics of each material. For each of the four assigned raw materials, the corresponding tests completed are displayed in Table 18. The tests performed are categorised as:

CBR	California Bearing Ratio
ATT	Atterberg Limits
PSD	Particle Size Distribution
MDR	Moisture Density Relationship

Table 18. Testing Phase 1: Raw Materials

Testing Phase # 1: Raw Materials					
Raw Materials Description	**Raw Material ID #**	**Test**			
Type 2.3 Gravel	1	CBR	ATT	PSD	MDR
Pittsworth Alluvial	2	CBR	ATT	PSD	MDR
Redlands Silt	3	CBR	ATT	PSD	MDR
Wallum Court Clay	4	CBR	ATT	PSD	MDR

4.4.2 Testing Phase 2: Blended Raw Materials

Testing phase 2 consisted of testing the blended raw materials by Border-Tek that made up the nine pavement types. An additional column in Table 19 is shown indicating the three variations in proportion of subgrade mixed into the gravel, being 20%, 35% and 50%.

Table 19. Testing Phase 2: Blended Raw Materials

Testing Phase # 2: Blended Raw Materials				
Pavement Type	**Raw Materials (RM)**	**RM Proportions (%)**	**Test**	
PT1	1 and 2	80/20	ATT	MDR
PT2	1 and 2	65/35	ATT	MDR
PT3	1 and 2	50/50	ATT	MDR
PT4	1 and 3	80/20	ATT	MDR
PT5	1 and 3	65/35	ATT	MDR
PT6	1 and 3	50/50	ATT	MDR
PT7	1 and 4	80/20	ATT	MDR
PT8	1 and 4	65/35	ATT	MDR
PT9	1 and 4	50/50	ATT	MDR

4.4.3 Experimental Testing Phases: Phase 3 and 4

Unconfined Compressive Strength (UCS) testing (carried out by Border-Tek) occurred on 72 basegrade samples treated with multiple trial mix designs across three trial mix design phases as summarised in Table 12.

The three phases were developed with the binder type being the distinguishing element. The nine pavement types described earlier (PT1 – PT9) comprising three subgrade materials and three different proportions of the subgrade with the gravel were mixed with the three combinations of the lime, cement, flyash and slag binders. Variations in binder application rates (quantity by %) were also trialled to ensure an adequate sample size for data analysis.

The three mix designs that were trialled in the research testing program are tabulated below. Phase 3a and Phase 3b reflect mix designs comprising lime/cement/flyash triple blends and a slag/lime general blend. These two sub phases were conducted with the binders mixed into the nine basegrade pavements with no delay between incorporation of each individual binder element.

Phase 4 reflected mix designs comprising lime/cement/flyash triple blends similar to Phase 3a. This phase however was conducted with the lime mixed into the nine basegrade pavements and cured under ambient temperature conditions for 24 hours (ie. lime pre-treatment). These samples were then manually broken down in the laboratory and a 70/30 cement flyash (GB) was incorporated. This phase was aimed at assessing the effect of lime pre-treatment and being allowed to undergo amelioration before addition of the cementitious blend to compare with the single day application of all the triple blend constituents.

Each of the above three trial mix designs simulate previous evidence of what is now termed basegrade stabilisation that has occurred in local councils or has been in use by QLD TMR. All binder types, blends and application rates are summarised in Table 20.

Table 20. Research Experimental Testing Phases 3 and 4

Testing Phase 3a	**Testing Phase 3b**	**Testing Phase 4**
Lime/Cement/Flyash Triple Blends	**Slag/Lime General Blends**	**Lime Pre-Treatment + Cement/Flyash Triple Blends**
30/40/30 @ 3%, 5%, 7%	60/40 @ 5%, 7%	60/30/10 (3% lime & 2% 70/30 GB)
40/40/20 @ 3%, 5%, 7%		50/35/15 (3% lime & 3% 70/30 GB)
50/30/20 @ 3%, 5%, 7%		45/40/15 (3% lime & 4% 70/30 GB)
Single Day Process		Two Day Process

Although the proportions of 85/15 are the most common slag/lime blends (Austroads, 2018), the 60/40 slag/lime ratio has been selected for this research based on prior experience using this combination at Port Macquarie Hastings Council as described in the Case Studies section. The reason for adopting only two application rates for testing phase 3b (5% and 7%) was due to budget constraints.

Prior to UCS testing in phases 3 and 4, moisture density relationships were tested on samples blended with 5% binder content. This allowed for adjustment to the optimum moisture content and maximum dry density when a binder is added to a host material. This concept is illustrated in Figure 38 showing how these properties are altered when a stabilising binder is introduced.

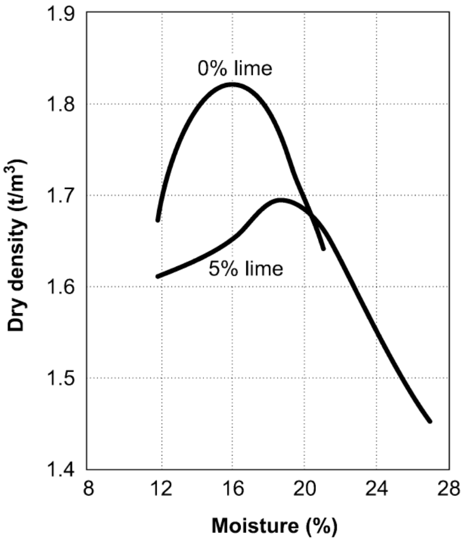


Figure 38. Effect on OMC and MDD with Addition of Binder (Austroads, 2019a)

4.4.4 Testing Phase 3a: Lime/Cement/Flyash Triple Blends

The specific details of testing phase 3a and the associated laboratory tests are shown in Table 21.

Table 21. Testing Phase 3a: Lime/Cement/Flyash Triple Blends

Testing Phase # 3a: Lime/Cement/Flyash Triple Blends							
Pavement Type	Raw Materials (RM)	RM Proportions (%)	Binder Proportions (%)	Binder %	Test		
PT1	1 and 2	80/20	30/40/30	3			UCS
PT1	1 and 2	80/20	30/40/30	5	ATT	MDR	UCS
PT1	1 and 2	80/20	30/40/30	7			UCS
PT2	1 and 2	65/35	40/40/20	3			UCS
PT2	1 and 2	65/35	40/40/20	5	ATT	MDR	UCS
PT2	1 and 2	65/35	40/40/20	7			UCS
PT3	1 and 2	50/50	50/30/20	3			UCS
PT3	1 and 2	50/50	50/30/20	5	ATT	MDR	UCS
PT3	1 and 2	50/50	50/30/20	7			UCS
PT4	1 and 3	80/20	30/40/30	3			UCS
PT4	1 and 3	80/20	30/40/30	5	ATT	MDR	UCS
PT4	1 and 3	80/20	30/40/30	7			UCS
PT5	1 and 3	65/35	40/40/20	3			UCS
PT5	1 and 3	65/35	40/40/20	5	ATT	MDR	UCS
PT5	1 and 3	65/35	40/40/20	7			UCS
PT6	1 and 3	50/50	50/30/20	3			UCS
PT6	1 and 3	50/50	50/30/20	5	ATT	MDR	UCS
PT6	1 and 3	50/50	50/30/20	7			UCS
PT7	1 and 4	80/20	30/40/30	3			UCS
PT7	1 and 4	80/20	30/40/30	5	ATT	MDR	UCS
PT7	1 and 4	80/20	30/40/30	7			UCS
PT8	1 and 4	65/35	40/40/20	3			UCS
PT8	1 and 4	65/35	40/40/20	5	ATT	MDR	UCS
PT8	1 and 4	65/35	40/40/20	7			UCS
PT9	1 and 4	50/50	50/30/20	3			UCS
PT9	1 and 4	50/50	50/30/20	5	ATT	MDR	UCS
PT9	1 and 4	50/50	50/30/20	7			UCS

The lime, cement and flyash constituents of the triple blend in this phase of the research remained constant, however the proportion of lime was adjusted from 30% to 50% in 10% increments. This adjustment was based on the proportion of subgrade in the basegrade pavement. Pavement types with 20% subgrade had 30% lime in the triple blend. Pavement types with 35% subgrade had 40% lime in the triple blend and pavement types with 50% subgrade had 50% lime in the triple blend. This formed part of the initial hypothesis that with increasing subgrade content, an increasing lime content would be required to treat the subgrade portion.

4.4.5 Testing Phase 3b: Slag/Lime General Blends

The specific details of testing phase 3b and the associated laboratory tests are shown in Table 22.

Table 22. Testing Phase 3b: Slag/Lime General Blends

Testing Phase # 3b: Slag/Lime General Blends							
Pavement Type	Raw Materials (RM)	RM Proportions (%)	Binder Proportions (%)	Binder %	Test		
PT1	1 and 2	80/20	60/40	5			UCS
PT2	1 and 2	65/35	60/40	5	ATT	MDR	UCS
PT3	1 and 2	50/50	60/40	5			UCS
PT1	1 and 2	80/20	60/40	7			UCS
PT2	1 and 2	65/35	60/40	7			UCS
PT3	1 and 2	50/50	60/40	7			UCS
PT4	1 and 3	80/20	60/40	5			UCS
PT5	1 and 3	65/35	60/40	5	ATT	MDR	UCS
PT6	1 and 3	50/50	60/40	5			UCS
PT4	1 and 3	80/20	60/40	7			UCS
PT5	1 and 3	65/35	60/40	7			UCS
PT6	1 and 3	50/50	60/40	7			UCS
PT7	1 and 4	80/20	60/40	5			UCS
PT8	1 and 4	65/35	60/40	5	ATT	MDR	UCS
PT9	1 and 4	50/50	60/40	5			UCS
PT7	1 and 4	80/20	60/40	7			UCS
PT8	1 and 4	65/35	60/40	7			UCS
PT9	1 and 4	50/50	60/40	7			UCS

4.4.6 Testing Phase 4: Lime Ameliorated Cement/Flyash General Blends

For phase 4, the US Army Corps of Engineers stabilisation design and construction manual reflects on the use of lime as a preliminary treatment to plastic soils prior to the use of a cementitious binder (US Army Corps, 1984). It states that although lime treatments used in isolation are often measured by the long term strength gain of the treated material, a lime pre-treatment approach should be measured by the primary objective of the pre-treatment, which is typically a reduction in plasticity index. Therefore lime demand testing or UCS testing is not required to determine the minimum quantity of lime required, as those tests are associated with long term strength parameters for lime stabilisation. Addition of cementitious binders after the lime pre-treatment provides the governing strength characteristics.

In testing phase 3a, the triple blend constituents were adjusted with increasing lime content as the proportion of subgrade increased. In this testing phase, the lime was maintained at a constant application rate of 3% and was mixed into the basegrade samples 24 hours before the cement/flyash was added. This process is termed amelioration and provides time for the lime to react more thoroughly with the clay elements before being subjected to a strengthening binder. The purpose of this testing phase was to examine the effects of the lime amelioration period to assess if highly plastic clay subgrades that are mixed into pavement gravels at high proportions can benefit more than a single day approach where no amelioration occurs.

In this testing phase, the cement/flyash was maintained at proportions of 70/30. This is consistent with many areas of Australia that use cement/flyash.

The testing program illustrated in Table 23 highlights the use of the 70/30 cementitious general blend in all trials. These were all conducted after the addition of 3% hydrated lime and 24 hours amelioration was completed.

Table 23. Testing Phase 4: Lime Ameliorated Cement/Flyash General Blends

Testing Phase # 4: 3% Lime on Day 1, Cement/Flyash (GB) on Day 2							
Pavement Type	Raw Materials (RM)	RM Proportions (%)	GB Binder Proportions (%)	Binder %	Test		
PT1	1 and 2	80/20	70/30	2			UCS
PT2	1 and 2	65/35	70/30	2	ATT	MDR	UCS
PT3	1 and 2	50/50	70/30	2			UCS
PT4	1 and 3	80/20	70/30	2			UCS
PT5	1 and 3	65/35	70/30	2	ATT	MDR	UCS
PT6	1 and 3	50/50	70/30	2			UCS
PT7	1 and 4	80/20	70/30	2			UCS
PT8	1 and 4	65/35	70/30	2	ATT	MDR	UCS
PT9	1 and 4	50/50	70/30	2			UCS
PT1	1 and 2	80/20	70/30	3			UCS
PT2	1 and 2	65/35	70/30	3	ATT	MDR	UCS
PT3	1 and 2	50/50	70/30	3			UCS
PT4	1 and 3	80/20	70/30	3			UCS
PT5	1 and 3	65/35	70/30	3	ATT	MDR	UCS
PT6	1 and 3	50/50	70/30	3			UCS
PT7	1 and 4	80/20	70/30	3			UCS
PT8	1 and 4	65/35	70/30	3	ATT	MDR	UCS
PT9	1 and 4	50/50	70/30	3			UCS
PT1	1 and 2	80/20	70/30	4			UCS
PT2	1 and 2	65/35	70/30	4	ATT	MDR	UCS
PT3	1 and 2	50/50	70/30	4			UCS
PT4	1 and 3	80/20	70/30	4			UCS
PT5	1 and 3	65/35	70/30	4	ATT	MDR	UCS
PT6	1 and 3	50/50	70/30	4			UCS
PT7	1 and 4	80/20	70/30	4			UCS
PT8	1 and 4	65/35	70/30	4	ATT	MDR	UCS
PT9	1 and 4	50/50	70/30	4			UCS

4.5 Laboratory Test Methods

The test methods selected for use in this research predominantly reflect those published by the Queensland Department of Transport and Main Roads (TMR, 2020c). These test methods are all underpinned by the respective Australian Standard where one exists for the nominated test method (Standards Australia, 2000; Standards Australia, 2005). The primary reason for selecting these test methods was due to TMR's extensive experience with stabilised materials and their enhanced test methods that have evolved over many years. Some of their test methods are particularly suited to stabilised materials where Australian Standard test methods do not otherwise exist.

Test Methods

AS:	Australian Standard
Q:	Queensland Government, Department of Transport and Main Roads

Preparation

Q101:	Preparation of disturbed samples
Q101A:	Sample combination and splitting
Q101B:	Representative sample reduction

Tests

AS1289.2.1.1	Moisture Content of Soil
Q103A:	Particle size distribution of soil - wet sieving
Q104A:	Liquid limit of soil
Q104B:	Liquid limit of soil - one point
Q105:	Plastic limit and plasticity index of soil
Q106:	Linear shrinkage of soil
Q142A:	Dry density - moisture relationship of soils and crushed rock – standard
Q115:	Unconfined compressive strength of stabilised materials
Q135A:	Addition of stabilising agents
Q135B:	Curing moulded specimens of stabilised material
Q145A:	Laboratory compaction to nominated levels of dry density and moisture content

4.6 Data Analysis

Analysis of the laboratory results included various evaluations of the strength results compared to the trial mix designs and nine pavement types. Multiple regression and correlation analyses were used to identify relationships between dependent and independent variables used in the research. The objective was to establish good correlations between variables that enabled the development of a mix design procedure based on a number of dependent and independent variables.

The independent variables are the nine basegrade pavements comprising a proportion of base and subgrade materials (PT1 – PT9), UCS curing period and the trial mix designs comprising different binder types, different binder quantities and alterations to the timing of binder addition.

The dependent variables for the nine untreated basegrade pavements are particle size distribution (PSD), linear shrinkage, plasticity index and moisture-density relationship. The dependent variables for the treated materials are UCS, linear shrinkage, plasticity index and moisture-density relationship. Test result relationships that were evaluated included the following:

- UCS v binder type;
- UCS v basegrade pavement type (base % versus subgrade %);
- UCS v subgrade type;
- UCS v lime proportion in the binder;
- UCS v binder application rate (%);
- UCS v basegrade pavement linear shrinkage;
- UCS v basegrade pavement plasticity index;
- UCS v untreated basegrade pavement PSD (% passing the 0.425mm sieve);
- UCS v untreated basegrade pavement PSD (% passing the 0.075mm sieve);
- UCS v untreated basegrade pavement fines ratio (% passing 0.075mm sieve divided by % passing 0.425mm sieve);
- Untreated linear shrinkage v treated linear shrinkage;
- Untreated plasticity index v treated plasticity index.

Optimisation has been defined as the binder type that requires the least amount of binder (cheaper) that can achieve the desired strength (1MPa < UCS < 2MPa) after a period of 28 days curing. All results have been presented graphically with outcomes derived from Microsoft Excel.

It was recognised in the analysis of the results that the definition of acceptable results was confined to a range (1MPa < UCS < 2MPa), rather than a specific value. Further, the intention with testing samples at various binder application rates was to produce results that were below, within and above the target strength range. Therefore it was expected to observe multiple complying and non-complying results that would assist in the formulation of mix design procedure input variables. These would ultimately provide trial mix design guidance that would also produce results below, within and above the target strength range, but have an increased probability of being within the range.

4.7 Results Hypothesis

It has been hypothesized that the following results would be produced from the research:

- An increase in strength (UCS) with increasing binder application rate.
- A decrease in strength (UCS) with increasing proportions of subgrade material.
- A decrease in strength (UCS) with increasing linear shrinkage and plasticity of the subgrade material.
- An increase in strength (UCS) with the addition of the triple blend binders over 2 days, due to the positive effect the lime amelioration will have on the subgrade components of the basegrade pavement. However this is expected to have less of an effect where the subgrade has higher silt content compared to clay content.

A mix design procedure in the form of a flowchart has been developed based on preliminary material properties of base and subgrade materials (eg. particle size distribution, linear shrinkage, plasticity index) and proportions of subgrade incorporated into the granular material.

5. EXPERIMENTAL RESULTS

All laboratory test results detailed in this section have been tabled according to the testing phase. Although previously described, a summary of each testing phase is provided below.

Test Phase 1: Testing host material characteristics of each of the four raw materials

Test Phase 2: Testing host material characteristics of each of the nine pavement types

Test Phase 3a: Lime/Cement/Flyash Triple Blend UCS testing

Test Phase 3b: Slag/Lime Blend UCS testing

Test Phase 4: 70/30 Cement/Flyash Blend UCS testing, pre-treated with 3% lime

Test reports from all laboratory work are contained in Appendix B through F for each the above test phases.

5.1 Phase 1 Test Results: Raw Materials

Table 24 summarises the host material properties of the four individual materials as detailed in the research program (Section 4.4.1).

Table 24. Raw Material Characteristics

Raw Material ID #	1	2	3	4
Property	**Type 2.3 Gravel**	**Pittsworth Alluvial**	**Redlands Silt**	**Wallum Court Clay**
Liquid Limit (%)	19.6	82.4	65.4	38.8
Plastic Limit (%)	17.6	33	37	24.6
Plasticity Index (%)	2.0	49.4	28.4	14.2
Linear Shrinkage (%)	1.4	21.4	16	3.4
Maximum Dry Density (t/m^3)	2.18	1.34	1.35	1.68
Optimum Moisture Content (%)	8.5	29.5	38	21
4 Day Soaked CBR (%)	70	1.5	2.5	8
Swell (%)	0.0	0.8	0.3	1.9

The swell characteristics of the Wallum Court Clay indicate the material has a medium expansive classification (Austroads, 2017).

Figure 39 shows the variation in CBR between the gravel and the three subgrade materials. Subgrade CBR's ranging from 1.5% up to 8% are considered representative of many plastic clays and silts found in local government roads across Australia.

Figure 40 illustrates the consistency limits of each material while Figure 41 shows the linear shrinkage test specimens.

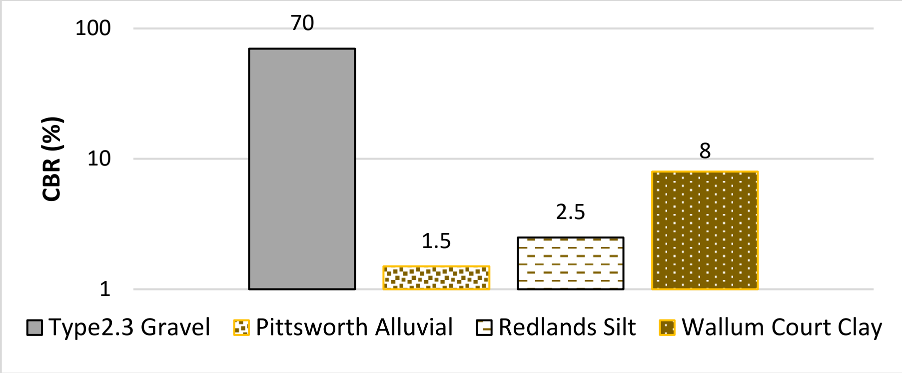


Figure 39. Raw Materials CBR

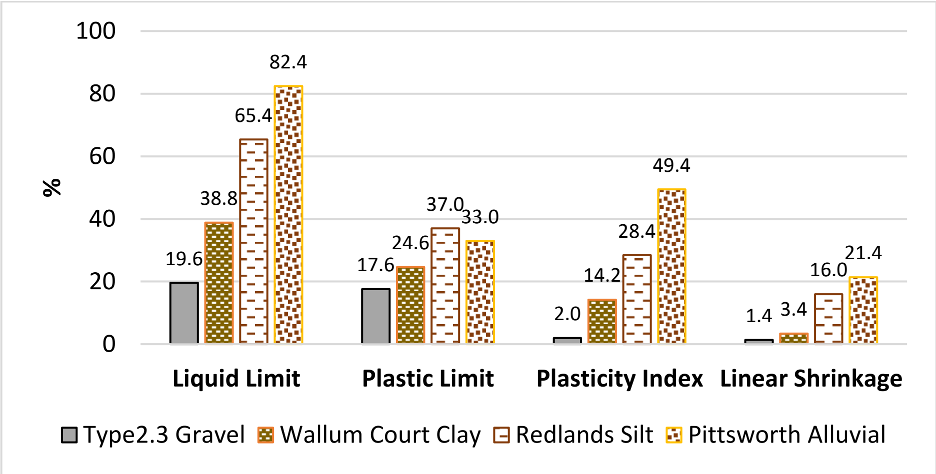


Figure 40. Consistency Limits: Raw Materials

Figure 41. Linear Shrinkage: Raw Materials (Border-Tek, 2020)

The modified Casagrande chart shown in Figure 42 is used for classifying silts and clays according to their behaviour (TMR, 2019a). The three subgrade materials used in this research are highlighted based on their liquid limit and plasticity index properties. Whilst there are a significantly high number of different subgrade materials types across the Australian landscape, these three provide a wide spread based on the modified Casagrande chart.

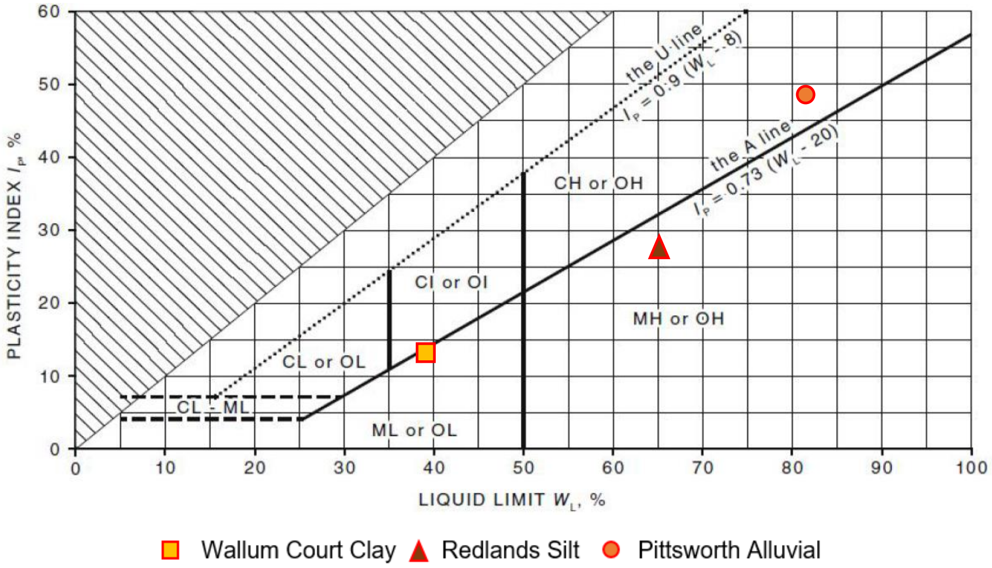


Figure 42. Soil Classification: Raw Materials

According to TMR's definitions for plasticity as detailed in the Table 25, the three subgrade materials are defined as having medium and high plasticity.

Table 25. Descriptive Terms for Plasticity (TMR, 2019a)

Descriptive Term	Silt Liquid Limit Range	Clay Liquid Limit Range	Research Subgrade
Non-plastic	N/A	N/A	-
Low plasticity	≤ 50	≤ 35	-
Medium plasticity	N/A	> 35 and ≤ 50	Wallum Court Clay
High plasticity	> 50	> 50	Redlands Silt / Pittsworth Alluvial

The PSD curves for each individual material are illustrated in Figure 43. Whilst not shown in the figure, the type 2.3 gravel complies with the upper and lower grading limits specified (TMR, 2020b).

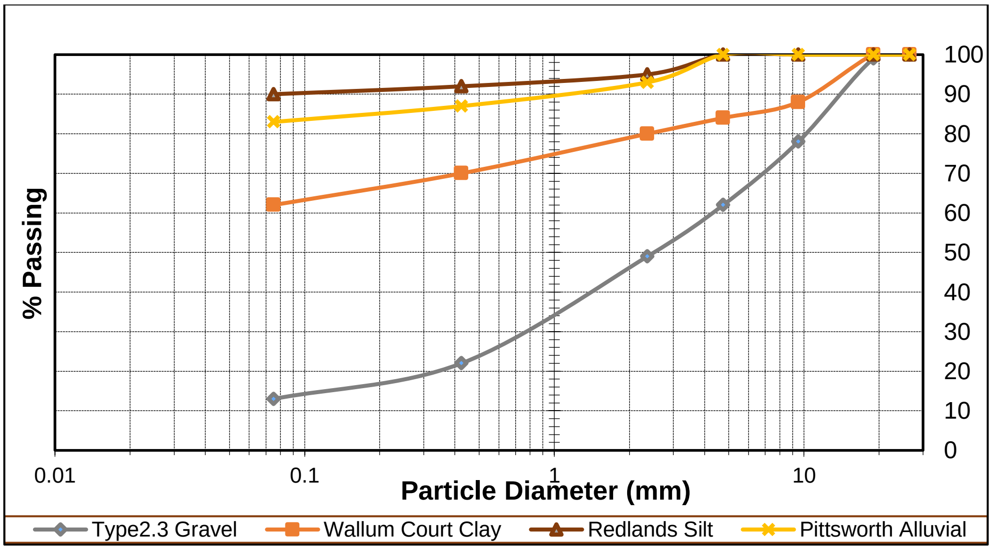


Figure 43. Particle Size Distribution: Raw Materials

5.2 Phase 2 Test Results: Blended Raw Materials

Table 26 summarises the properties obtained for the nine pavement types. None of these pavement types have had any stabilising binders added in this phase of the testing. These properties are those that are expected to reflect field conditions in situations where various subgrade materials are stabilised with existing pavement materials.

Table 26. Blended Raw Material Characteristics: PT1-PT9

Subgrade Material	Pittsworth Alluvial			Redlands Silt			Wallum Court Clay		
Pavement Type	**PT1**	**PT2**	**PT3**	**PT4**	**PT5**	**PT6**	**PT7**	**PT8**	**PT9**
Gravel/Subgrade Proportions	**80/20**	**65/35**	**50/50**	**80/20**	**65/35**	**50/50**	**80/20**	**65/35**	**50/50**
Liquid Limit (%)	36.4	69.6	74.0	38.2	59.0	61.0	25.2	32.0	36.0
Plastic Limit (%)	15.6	31.0	32.8	16.4	28.8	30.2	16.4	23.0	21.4
Plasticity Index (%)	20.8	38.6	41.2	21.8	30.2	30.8	8.8	9.0	14.6
Linear Shrinkage (%)	6.0	13.2	16.6	10.0	10.0	12.0	3.4	6.6	6.6
Maximum Dry Density (t/m^3)	2.00	1.85	1.76	2.05	1.89	1.82	2.10	2.07	1.96
Optimum Moisture Content (%)	12.5	15.5	18.5	12.0	16.0	18.0	10.0	11.0	12.0
Passing 0.425mm Sieve (%)	35	45	55	36	47	57	32	39	46
Passing 0.075mm Sieve (%)	27	38	48	28	40	52	23	30	38
Weighted Plasticity Index, WPI (%)	728	1737	2266	785	1419	1756	282	351	672
Weighted Linear Shrinkage, WLS (%)	210	594	913	360	470	684	109	257	304
Fines Ratio (%)	0.77	0.84	0.87	0.78	0.85	0.91	0.72	0.77	0.83

Figure 44 shows the particle size distribution curves for each of the nine pavement types. To put some context around these basegrade materials in terms of their PSD curves, Figure 45 and Figure 46 show the upper and lower compliance limits published for type 2.3 gravel (TMR, 2020b) and AustStab's limits recommended for cementitious stabilisation (AustStab, 2012).

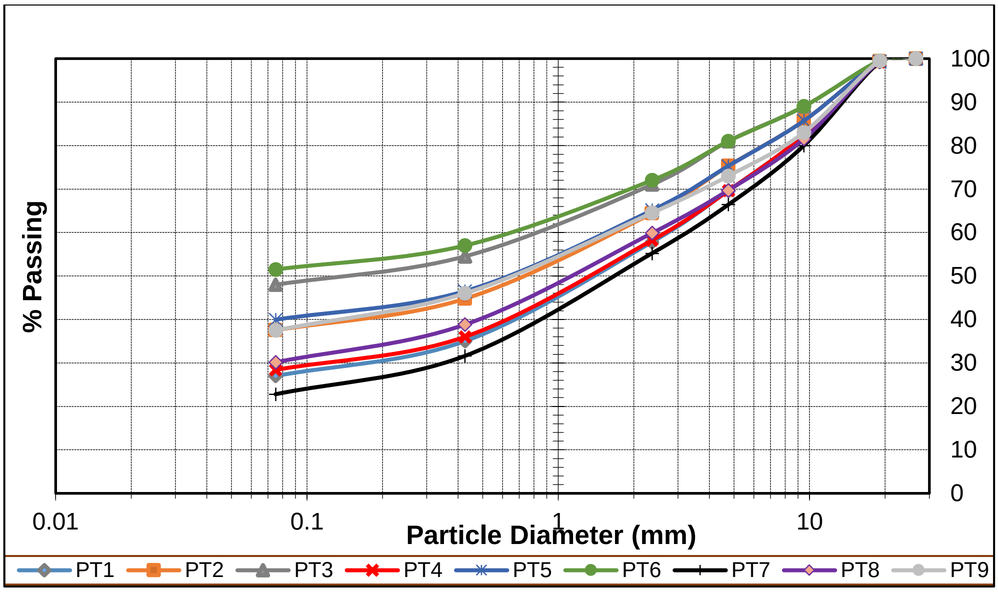


Figure 44. Particle Size Distribution: Blended Raw Materials

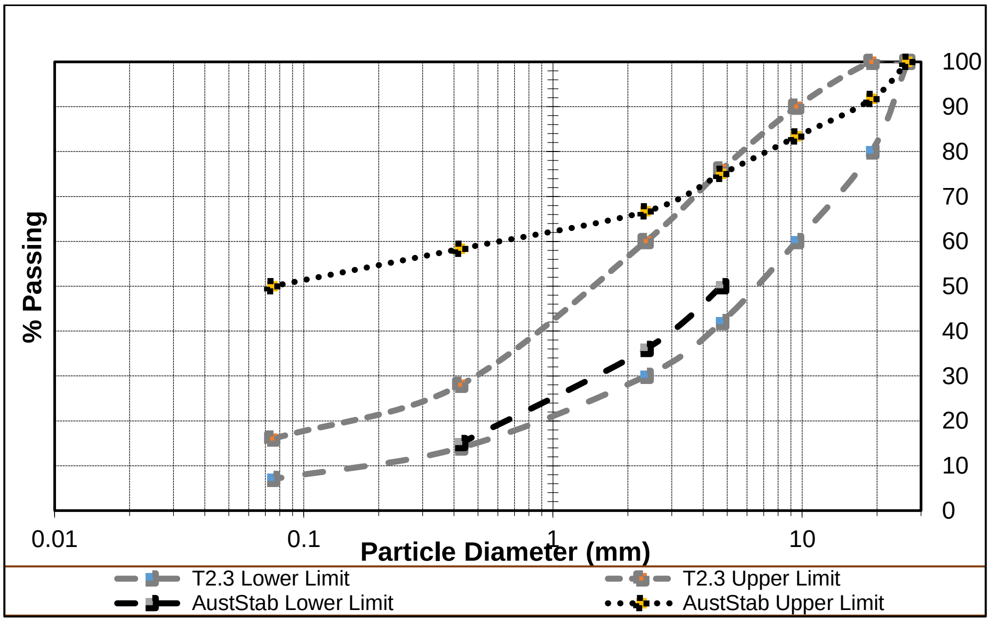


Figure 45. Particle Size Distribution: Compliance Limits

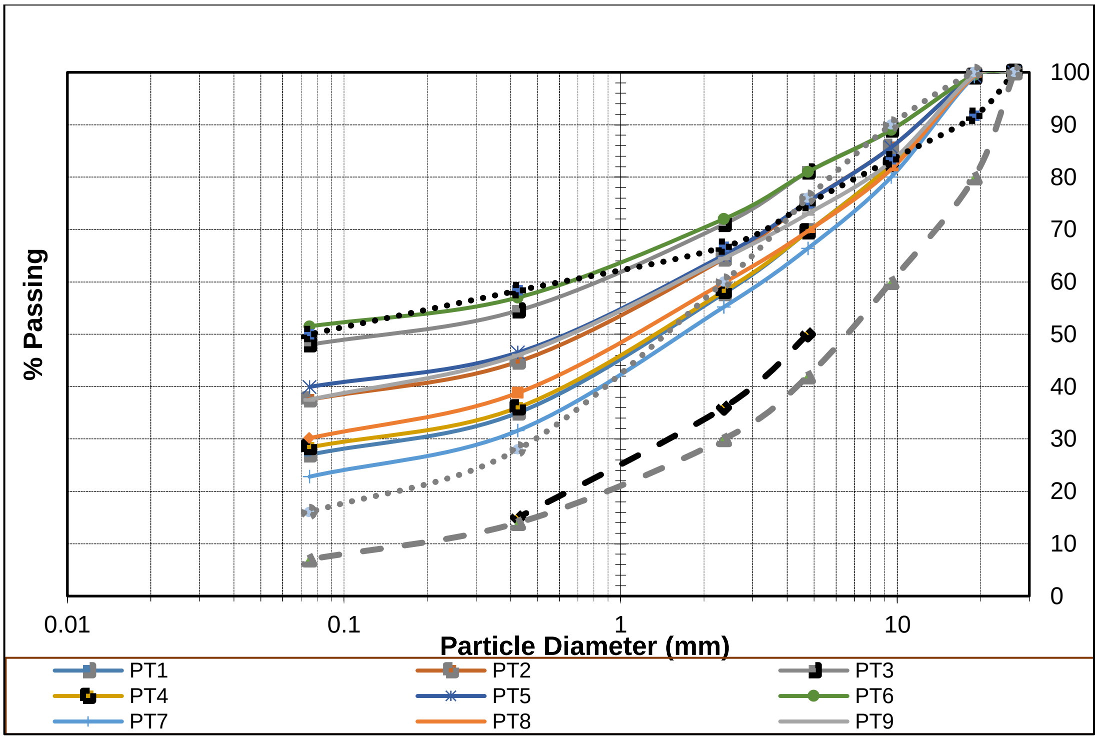


Figure 46. Particle Size Distribution: Blended Raw Materials v Compliance Limits

It is clear that none of the basegrade pavement types comply with typical grading curve limits required for pavement subbase quality materials, however most of the basegrade pavement types comply with the AustStab recommended limits with the exception of the coarse sieves from the 9.5mm and above.

Soil classifications of the nine basegrade pavement types have been plotted on the modified Casagrande chart in Figure 47.

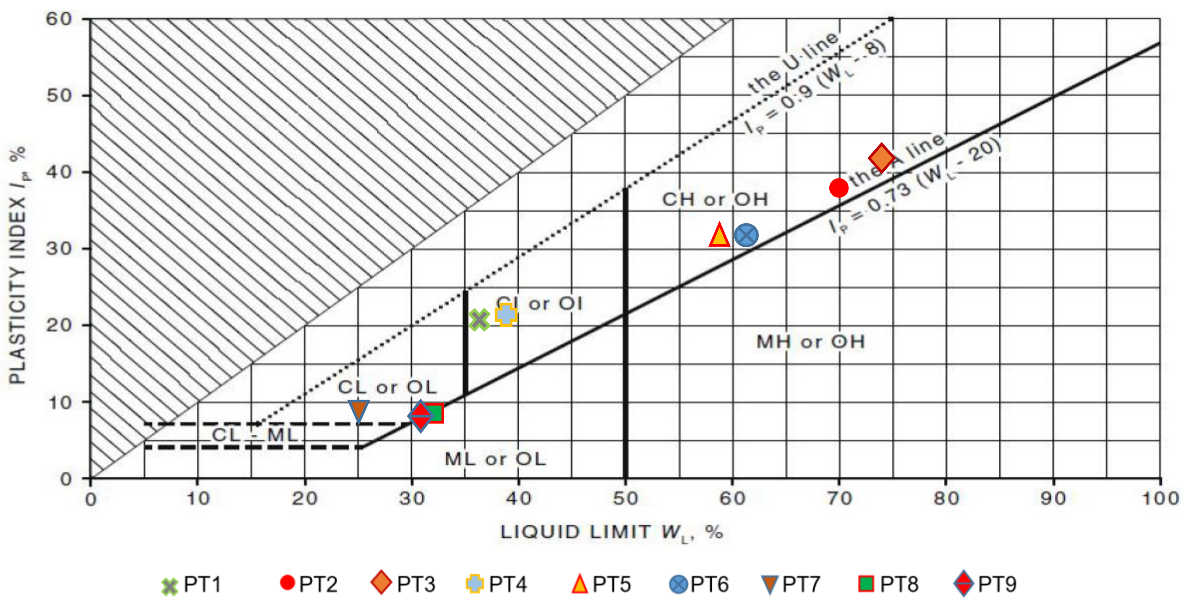


Figure 47. Soil Classification: Blended Raw Materials

Plasticity index (PI) and linear shrinkage (LS) material classifications are have been captured for comparison against the nine pavement types treated with stabilising binders. Both the PI and LS are illustrated in Figure 48.

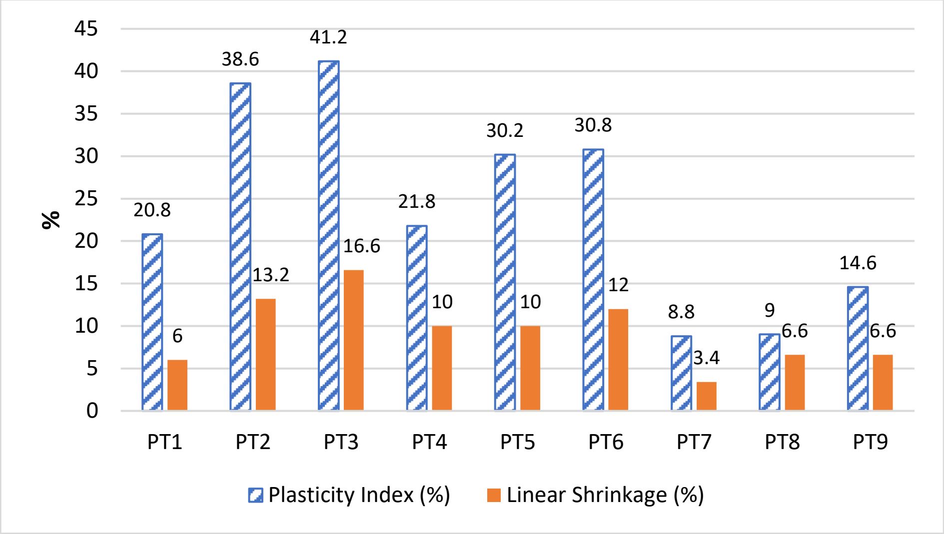


Figure 48. Blended Raw Materials Weighted Classifications

For a material to be regarded as having base layer qualities, a PI of 10% has been suggested as an upper limit (Serruto & Pardo, 2001; Austroads, 2019a) due to workability and moisture resistance benefits. Eight of the nine pavement types developed in this research would therefore not be deemed as having base layer qualities.

Linear shrinkage is required to be no greater than 3.5% (TMR, 2020b). The majority of these pavement types would therefore not be considered suitable as a base quality based on these properties alone.

This would be considered typical of what is encountered in many basegrade pavement situations in Australian local government jurisdictions. In fact, it is hypothesized that the PI and LS would generally be higher in a basegrade pavement that starts with an existing base gravel that has lower qualities than the gravel adopted in this research.

5.3 Phase 3a Test Results: Lime/Cement/Flyash Triple Blends

This section displays the test results from the first trials using triple blend binders, comprising lime, cement and flyash. Table 27 summarises the results of the various properties obtained during this testing phase, excluding strength test results. For the nine pavement types shown in Table 26, all test results are based on samples where 5% of the triple blend binder was added to the sample.

The MDD and OMC results shown in the Table 27 were used as targets for preparation of all UCS samples in this research phase, due to being the mid-point between the three application rates trialled (3%, 5%, 7%).

Table 27. Blended Raw Material Characteristics: PT1-PT9

Pavement Type	PT1	PT2	PT3	PT4	PT5	PT6	PT7	PT8	PT9
Raw Material Proportions (%)	**80/20**	**65/35**	**50/50**	**80/20**	**65/35**	**50/50**	**80/20**	**65/35**	**50/50**
Triple Blend Binder	**30/40/30**	**40/40/20**	**50/30/20**	**30/40/30**	**40/40/20**	**50/30/20**	**30/40/30**	**40/40/20**	**50/30/20**
Binder Application Rate (%)					**5**				
Liquid Limit (%)	51.0	51.2	53.6	55.2	53.8	51.0	27.2	40.2	39.0
Plastic Limit (%)	49.4	46.6	45.0	48.0	48.0	48.4	19.8	36.4	34.6
Plasticity Index (%)	1.6	4.6	8.6	7.2	5.8	2.6	7.4	3.8	4.4
Linear Shrinkage (%)	2.2	4.0	5.4	5.4	4.6	3.4	3.4	3.4	4.0
Maximum Dry Density, MDD (t/m^3)	2.02	1.88	1.75	2.05	1.93	1.83	2.09	2.02	1.95
Optimum Moisture Content, OMC (%)	11.0	15.0	18.0	10.5	13.5	15.5	10.5	11.5	12.5

Figure 49 illustrates two linear shrinkage samples at the completion of the testing period. The top and bottom samples correspond to 3.4% and 4.0% linear shrinkage for subgrade proportions of 35% and 50% respectively.

Figure 49. Linear Shrinkage Samples, PT8 (top) and PT9 (bottom) with 5% Lime/Cement/Flyash (Border-Tek, 2020)

The UCS results shown in Table 28 are from pavement types PT1, PT2 and PT3. These all contain the Pittsworth Alluvial subgrade clay.

Table 28. Lime/Cement/Flyash Triple Blend UCS Results: PT1-PT3

Pavement Type	**PT1**			**PT2**			**PT3**		
Base v Subgrade	80/20			65/35			50/50		
Triple Blend	30/40/30			40/40/20			50/30/20		
Application Rate (%)	3	5	7	3	5	7	3	5	7
UCS (MPa)	1.5	1.8	2.3	0.6	1.5	1.7	0.3	0.6	1.3

The UCS results shown in Table 29 are from pavement types PT4, PT5 and PT6. These all contain the Redlands Silt subgrade.

Table 29. Lime/Cement/Flyash Triple Blend UCS Results: PT4-PT6

Pavement Type	**PT4**			**PT5**			**PT6**		
Base v Subgrade	80/20			65/35			50/50		
Triple Blend	30/40/30			40/40/20			50/30/20		
Application Rate (%)	3	5	7	3	5	7	3	5	7
UCS (MPa)	1.9	2.0	3.1	1.1	1.9	1.9	0.6	1.6	1.3

The UCS results shown in Table 30 are from pavement types PT7, PT8 and PT9. These all contain the Wallum Court subgrade clay.

Table 30. Lime/Cement/Flyash Triple Blend UCS Results: PT7-PT9

Pavement Type	**PT7**			**PT8**			**PT9**		
Base v Subgrade	80/20			65/35			50/50		
Triple Blend	30/40/30			40/40/20			50/30/20		
Application Rate (%)	3	5	7	3	5	7	3	5	7
UCS (MPa)	0.8	1.3	1.8	1.0	1.5	2.0	1.0	1.3	1.8

Figure 50 and Figure 51 illustrate some of the UCS moulds during the 28 day curing stage and prior to being tested in the UCS testing apparatus (refer Figure 52).

Figure 50. UCS Samples in the 28 Day Curing Period (Border-Tek, 2020)

Figure 51. UCS Cast Samples (Border-Tek, 2020)

Figure 52. UCS Test Apparatus (Border-Tek, 2020)

5.4 Phase 3b Test Results: Slag/Lime General Blends

This section displays the test results from the trials using slag/lime binders, comprising 60% slag and 40% hydrated lime. Table 31 summarises the results of the various properties obtained during this testing phase, excluding strength test results. For the three pavement types shown in Table 31, all test results are based on samples where 5% of the slag/lime binder was added to the sample.

Table 31. Blended Material Characteristics: PT1-PT9

Pavement Type	**PT2**	**PT5**	**PT8**
Raw Material Proportions (%)		**65/35**	
60/40 Slag/Lime Application Rate (%)		**5**	
Liquid Limit (%)	46.2	53.0	39.0
Plastic Limit (%)	39.6	46.8	33.4
Plasticity Index (%)	6.6	6.2	5.6
Linear Shrinkage (%)	6.0	4.6	2.6
Maximum Dry Density, MDD (t/m^3)	1.91	1.96	2.05
Optimum Moisture Content, OMC (%)	13.5	14.0	11.0

The MDD and OMC results shown in the above table were used as targets for preparation of all UCS samples in this research phase. Although application rates of only 5% and 7% were trialled in this part of the research, moisture density relationships were performed on samples with 5% binder to replicate the moisture density relationship testing performed in testing phase 3a.

The UCS results shown in Table 32 are from pavement types PT1, PT2 and PT3. These all contain the Pittsworth Alluvial subgrade clay.

Table 32. Slag/Lime General Blend UCS Results: PT1-PT3

Pavement Type	**PT1**		**PT2**		**PT3**	
Base v Subgrade	80/20		65/35		50/50	
Slag/Lime				60/40		
Application Rate (%)	5	7	5	7	5	7
UCS (MPa)	2.9	3.3	1.2	2.0	0.7	0.9

The UCS results shown in Table 33 are from pavement types PT4, PT5 and PT6. These all contain the Redlands Silt subgrade.

Table 33. Slag/Lime General Blend UCS Results: PT4-PT6

Pavement Type	**PT4**		**PT5**		**PT6**	
Base v Subgrade	80/20		65/35		50/50	
Slag/Lime				60/40		
Application Rate (%)	5	7	5	7	5	7
UCS (MPa)	3.3	3.1	2.1	2.7	1.0	1.5

The UCS results shown in Table 34 are from pavement types PT7, PT8 and PT9. These all contain the Wallum Court subgrade clay.

Table 34. Slag/Lime General Blend UCS Results: PT7-PT9

Pavement Type	**PT7**		**PT8**		**PT9**	
Base v Subgrade	80/20		65/35		50/50	
Slag/Lime	60/40					
Application Rate (%)	5	7	5	7	5	7
UCS (MPa)	2.0	2.3	1.8	2.3	1.3	2.2

Figure 53 shows the process of mixing the binder with the basegrade material after being initially weighed by dry mass to determine the quantity of binder required to represent the research application rate of 5% or 7% in this phase of the testing.

Figure 53. Mixing Slag/Lime Binder with Basegrade Material (Border-Tek, 2020)

5.5 Phase 4 Test Results: Lime Ameliorated 70/30 Cement/Flyash General Blends

This section displays the test results from the trials using triple blend binders similar to testing phase 3a, comprising lime, cement and flyash. The 70/30 cement flyash has been termed a general blend cement, or 'GB' from this point on.

Table 35 summarises the results of the various properties obtained during this testing phase, excluding strength test results. For the three pavement types shown in Table 35, all test results are based on samples where 2%, 3% and 4% of the GB binder was added to the sample.

Table 35. Blended Material Characteristics: PT1-PT9

Pavement Type	**PT2**	**PT5**	**PT8**	**PT2**	**PT5**	**PT8**	**PT2**	**PT5**	**PT8**
Raw Material Proportions (%)	**65/35**								
70/30 Cement/Flyash Application Rate (%)	**2**			**3**			**4**		
Liquid Limit (%)	50.0	57.2	38.6	48.6	55.2	40.2	47.6	39.4	41.0
Plastic Limit (%)	40.8	53.0	34.2	41.6	52.6	35.8	42.6	34.0	36.0
Plasticity Index (%)	9.2	4.2	4.4	7.0	2.6	4.4	5.0	5.4	5.0
Linear Shrinkage (%)	8.0	6.0	5.0	7.6	4.0	3.4	4.0	4.0	3.4
Maximum Dry Density, MDD (t/m^3)	1.93	1.99	2.03	2.01	1.92	2.02	2.00	1.91	2.05
Optimum Moisture Content, OMC (%)	13.0	12.5	11.5	15.5	14.0	12.0	13.5	15.5	11.0

The MDD and OMC results shown in the above table were used as targets for preparation of all UCS samples in this research phase.

The UCS results shown in Table 36 are from pavement types PT1, PT2 and PT3. These all contain the Pittsworth Alluvial subgrade clay.

Table 36. Lime Ameliorated 70/30 GB UCS Results: PT1-PT3

Pavement Type	**PT1**			**PT2**			**PT3**		
Base v Subgrade	80/20			65/35			50/50		
Triple Blend	3% Lime + 70/30 Cement/Flyash								
70/30 Application Rate (%)	2	3	4	2	3	4	2	3	4
UCS (MPa)	1.6	1.9	3.1	1.3	1.0	2.1	0.5	1.2	0.8

The UCS results shown in Table 37 are from pavement types PT4, PT5 and PT6. These all contain the Redlands Silt subgrade.

Table 37. Lime Ameliorated 70/30 GB UCS Results: PT4-PT6

Pavement Type	**PT4**			**PT5**			**PT6**		
Base v Subgrade	80/20			65/35			50/50		
Triple Blend	3% Lime + 70/30 Cement/Flyash								
70/30 Application Rate (%)	2	3	4	2	3	4	2	3	4
UCS (MPa)	1.6	2.4	2.8	1.6	1.9	2.6	1.2	2.0	2.6

The UCS results shown in Table 38 are from pavement types PT7, PT8 and PT9. These all contain the Wallum Court subgrade clay.

Table 38. Lime Ameliorated 70/30 GB UCS Results: PT7-PT9

Pavement Type	**PT7**			**PT8**			**PT9**		
Base v Subgrade	80/20			65/35			50/50		
Triple Blend	3% Lime + 70/30 Cement/Flyash								
70/30 Application Rate (%)	2	3	4	2	3	4	2	3	4
UCS (MPa)	1.2	1.4	1.7	0.9	1.3	1.8	1.2	1.6	1.6

6 DISCUSSION OF RESULTS

The laboratory test results presented in the previous section have been prepared in numerous plots in this section to enable evaluation of the results. Where a graph is presented with UCS on the y-axis, the target strength range of 1-2MPa has been highlighted with a transparent box to provide clarity on where the results lie in relation to the lower and upper targets.

Each plot has been limited to a linear or second order polynomial regression to provide the fairest indication of the likely behaviour. However the strength of each regression is not as critical in the interpretation of the results, as the quantum of results that fit within the target strength range is of more importance. This is because interpretation of stabilisation mix design results is expected to observe a range that is wider than the target strength range. Hence why various binder application rates are chosen in a trial mix design, so as to allow results to span the target strength range.

Discussion of the graphical results have been presented in order of research test phase. A further section has also been provided that examines the combined results from each of the individual test phases. The objective was to establish clear trends between the UCS test results and host material properties from a holistic perspective that would allow formulation of a basegrade stabilisation mix design procedure.

As outlined in section 4.6, the data analysis has been undertaken with the following comparisons of laboratory test results.

- UCS v binder type;
- UCS v basegrade pavement type (base % versus subgrade %);
- UCS v subgrade type;
- UCS v lime proportion in the binder;
- UCS v binder application rate (%);
- UCS v basegrade pavement linear shrinkage;
- UCS v basegrade pavement plasticity index;
- UCS v untreated basegrade pavement PSD (% passing the 0.425mm sieve);
- UCS v untreated basegrade pavement PSD (% passing the 0.075mm sieve);
- UCS v untreated basegrade pavement fines ratio (% passing 0.075mm sieve divided by % passing 0.425mm sieve);
- Untreated linear shrinkage v treated linear shrinkage;
- Untreated plasticity index v treated plasticity index.

6.1 Phase 3a Test Results: Lime/Cement/Flyash Triple Blends

Figure 54 shows all UCS tests results for this testing phase against the three binder applications rates. As hypothesized, the general trend was an increase in UCS with an increase in application rate, regardless of the strength of the regression. The R squared value was expected to be low, as the UCS results were plotted against binder application rates for samples with variations in subgrade type and subgrade proportion.

74% of results were within the target strength range. The 5% application rate produced the highest level of complying results with 89% within the target range.

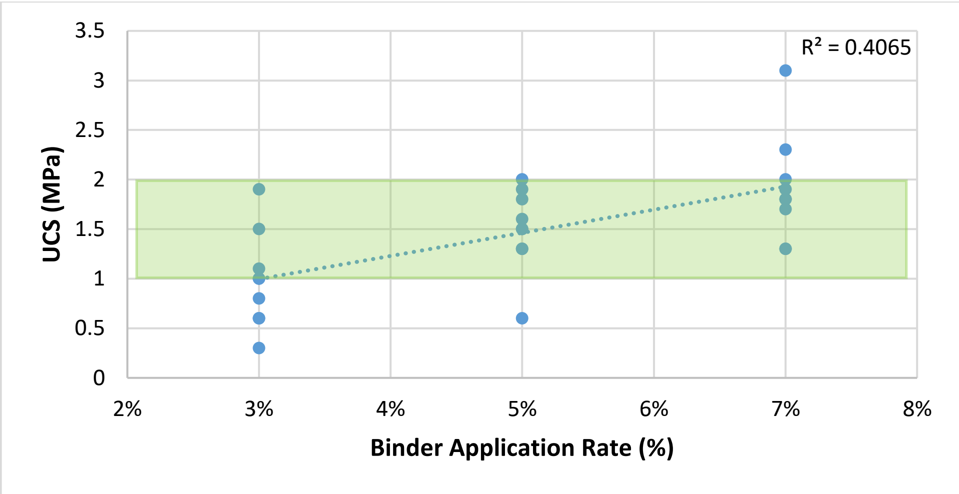


Figure 54. Phase 3a UCS v Triple Blend Application Rate

This data is explored in more detail in Figure 55 where the trends are displayed by subgrade type within the basegrade material.

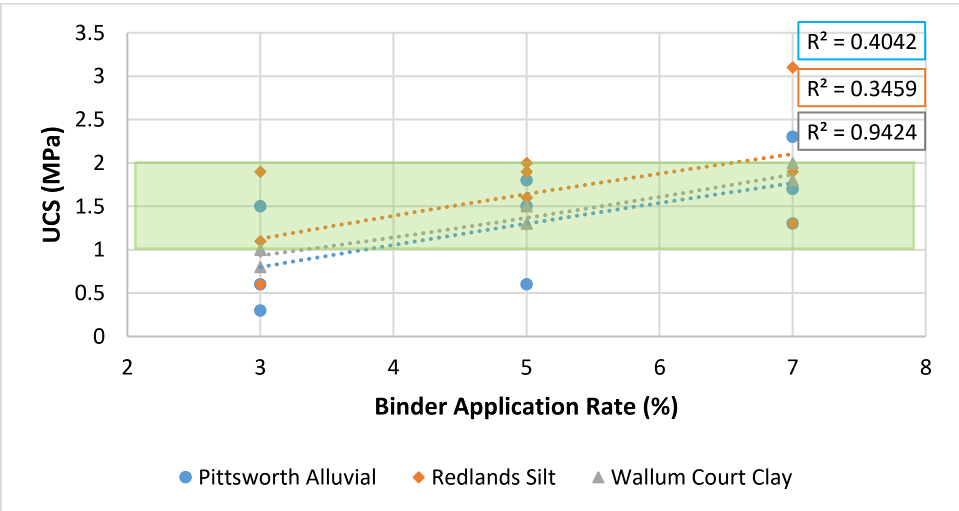


Figure 55. Phase 3a UCS v Triple Blend Application Rate (by subgrade type)

The UCS for each subgrade type within the basegrade mix increased at similar rates to each other with an increasing binder application rate (based on the slope of each trend line). The basegrade mix with Wallum Court Clay produced the highest level of compliance with 89% within the target range and a very high R squared (0.94). The basegrade mix with Pittsworth Alluvial produced the lowest with 56% within the target range.

The average change in UCS regardless of subgrade type was approximately 0.25MPa for every 1% increase in binder application rate.

Figure 56 shows the UCS test results compared to the percentage of lime within the triple blend, which ranged from 30% to 50%.

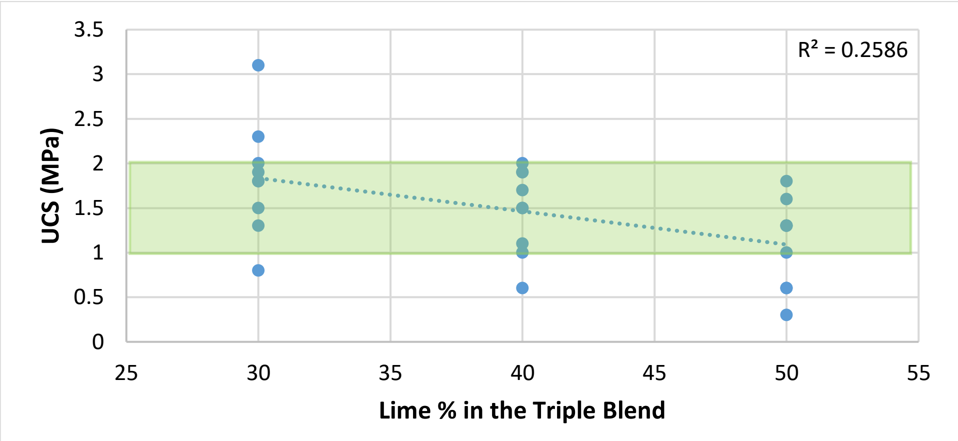


Figure 56. Phase 3a UCS v Lime Content in Triple Blend

The 40/40/20 triple blend was the most consistent of the three triple blends trialled, with 89% of results within the target strength range. This data is explored in more detail in Figure 57 where the trends are displayed by subgrade type within the basegrade material.

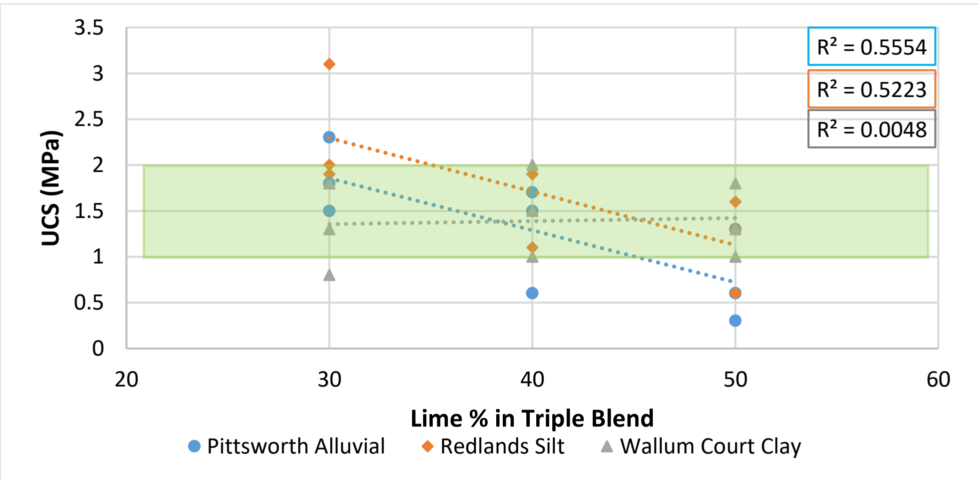


Figure 57. Phase 3a UCS v Lime Content in Triple Blend (by subgrade type)

These results suggest that the percentage of lime within the triple blend was most adequate for the basegrade mix with the Wallum Court Clay subgrade, as the average strength achieved was constant and approximately in the middle of the 1-2MPa target range. This was the objective where lime content was increased as the subgrade proportion increased.

Conversely with the basegrade mixes containing the Pittsworth Alluvial and Redlands Silt, the UCS decreased as the lime content increased. This may suggest that the lime content was not high enough for those pavement types.

Figure 58 shows the UCS compared to the percentage of subgrade contained in the basegrade pavement.

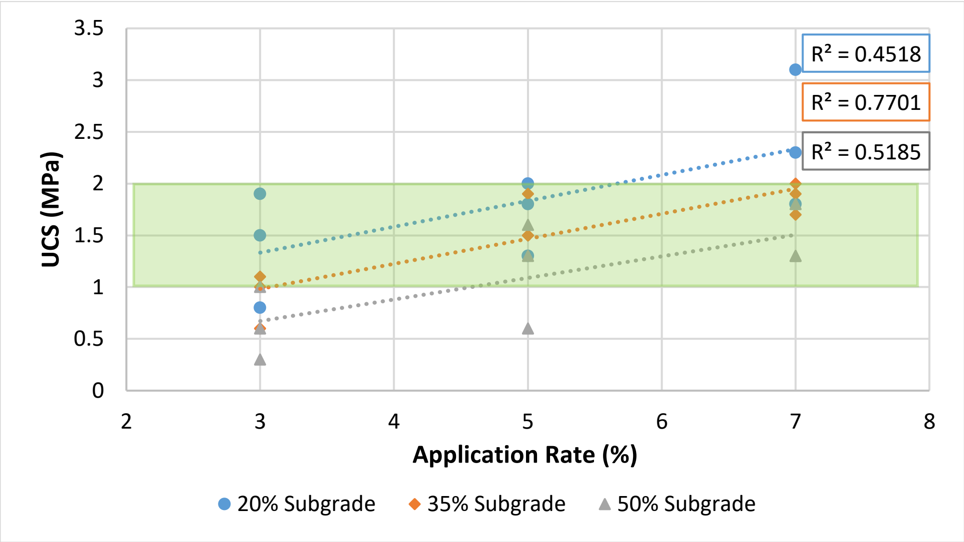


Figure 58. Phase 3a UCS v Subgrade Type

This plot is statistically significant due to the independent variable (ie. the subgrade) comprising multiple other variables such as particle size distribution and Atterberg Limits. It is clear that the strength increases with increasing binder application rate, regardless of the percentage of subgrade.

The pavement types with the highest level of compliance were those containing 35% subgrade materials. As expected, where non-compliance was observed with the 20% and 50% subgrade proportions, it was due to too much binder or not enough binder respectively.

The average change in UCS regardless of binder type or application rate was approximately 0.4MPa for every +/- 15% subgrade inclusion. This will be useful information when a trial mix design needs to be adjusted from any recommended application rates.

Figure 59 shows the UCS compared to the percentage passing the 0.075mm sieve of the untreated basegrade pavement types.

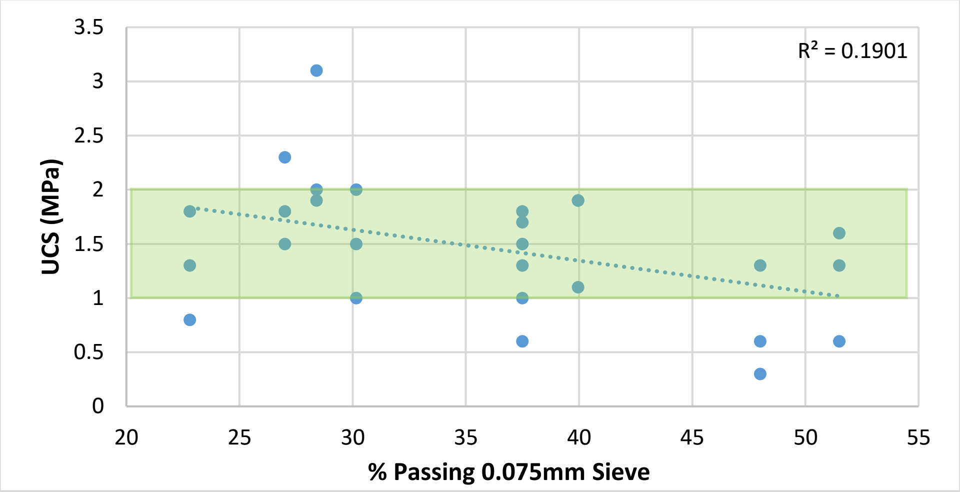


Figure 59. Phase 3a UCS v % Passing 0.075mm Sieve

The general trend shows a decrease in strength as the percent passing the 0.075mm sieve increases. Although the R squared is low, the trend is as expected. With increasing fines it is expected to observe diminishing strengths due to reduced larger particle interlock capability.

Conversely, the low regression outcome aligns with the dependent variable being evaluated (ie. the percent passing the 0.075mm sieve) due to other variables not being considered with this variable. Plasticity for example can vary for different materials that have the same percent passing.

This data is explored in more detail in Figure 60 where the trends are displayed by binder application rate. The majority of complying strengths occurred when the percent passing the 0.075mm sieve was between 20% and 40%.

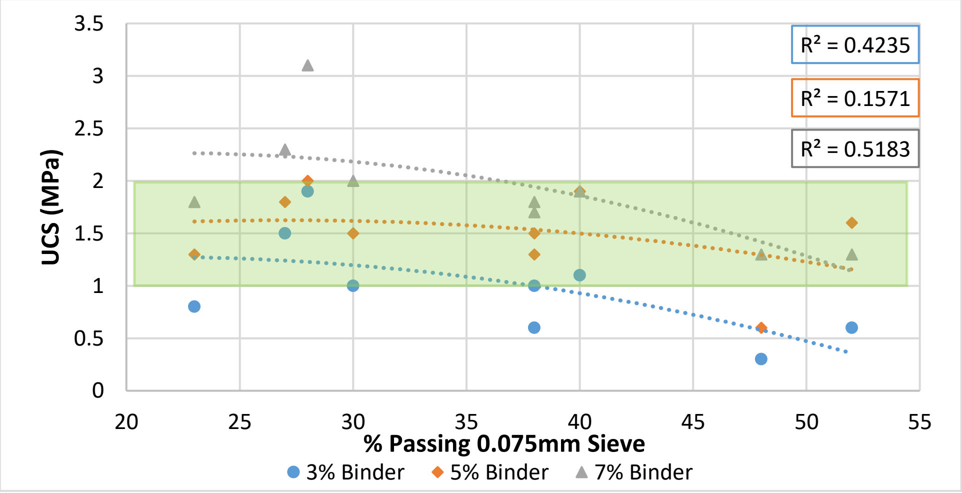


Figure 60. Phase 3a UCS v % Passing 0.075mm Sieve (by application rate)

Again the general trend was for a decrease in strength with an increasing fines content, regardless of the binder application rate.

Figure 61 shows a similar graph but with UCS compared to the percent passing the 0.425mm sieve of the untreated basegrade pavement types. This was done to enable a further graph (shown in Figure 62) to be presented combining the effects of the 0.075mm and 0.425mm sieves, termed the fines ratio (TMR, 2020b).

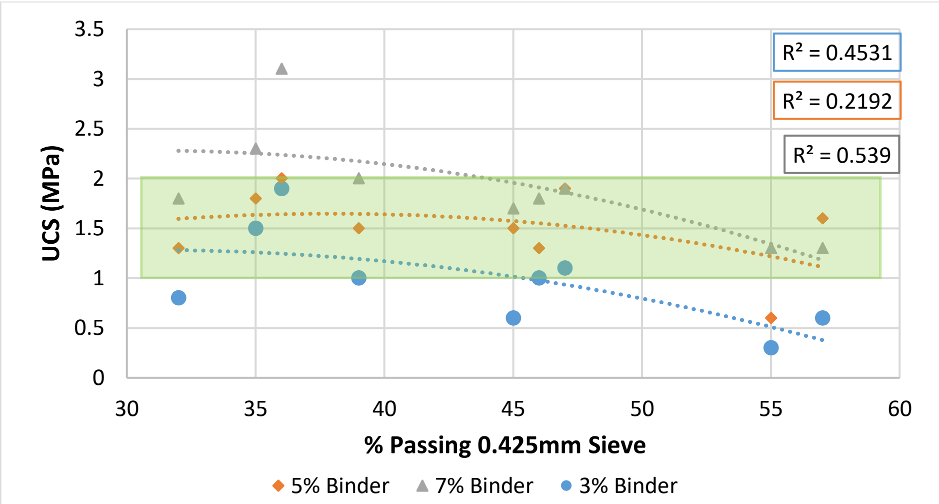


Figure 61. Phase 3a UCS v % Passing 0.425mm Sieve

The general trend shows a decrease in strength as the percent passing the 0.425mm sieve increases. The majority of complying strengths occurred when the percent passing the 0.425mm sieve was between 30% and 50%. Similarly, with Figure 59, this plot does not consider other variables such as plasticity that can affect the results for a material with the same percent passing the 0.425mm sieve.

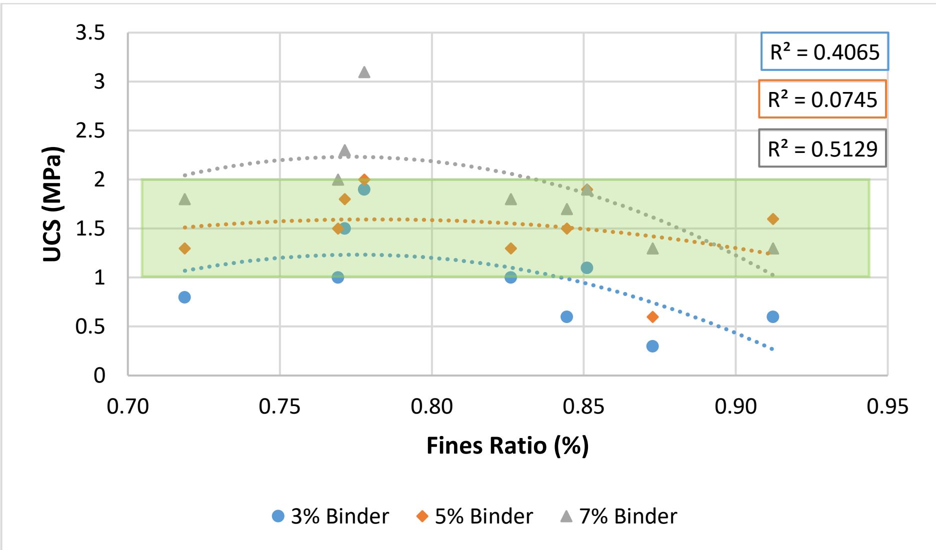


Figure 62. Phase 3a UCS v Fines Ratio

The general trend shows a decrease in strength as the fines ratio increases. The majority of complying strengths occurred when the fines ratio was between 0.70 and 0.85.

Although the previous three graphs visually appear to be the same in terms of the shape of the trend lines, they will continue to be examined in the remaining testing phases of the research to consider the potential establishment of mix design rules that encompass one or more of the PSD related strength data.

Figure 63 compares the plasticity index and linear shrinkage for the nine pavement types in the untreated state and the treated state (ie. after the addition of the triple blend binder).

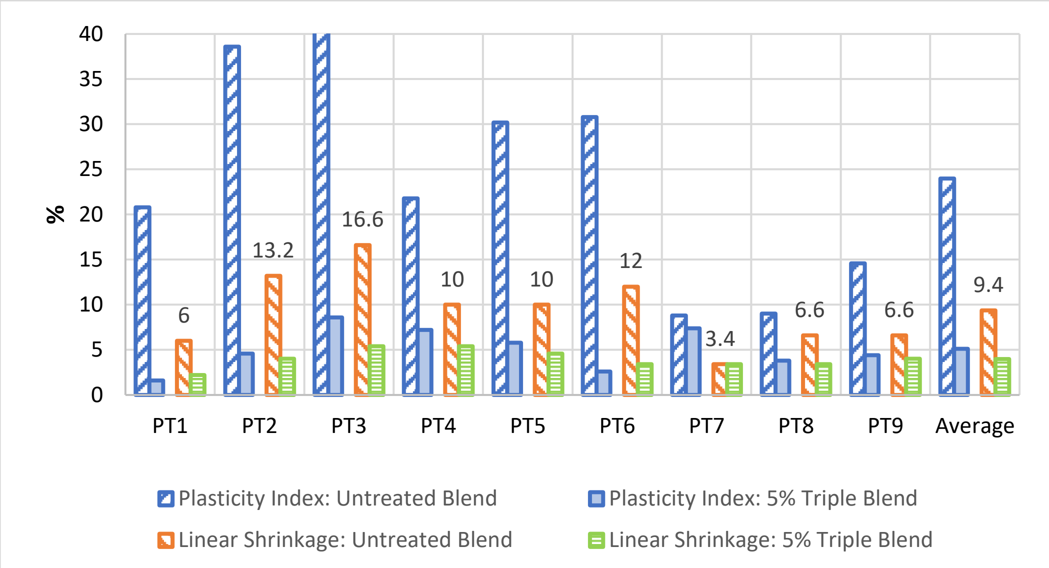


Figure 63. Phase 3a Plasticity Index and Linear Shrinkage: Pre and Post Treated Blends

The plasticity index and linear shrinkage of the untreated basegrade materials both showed a decreasing trend across the three subgrade types. This was expected as the same properties for the subgrade materials also followed that trend, with the Pittsworth Alluvial (in PT1-PT3) having the highest PI and LS and the Wallum Court Clay (in PT7-PT9) having the lowest PI and LS.

The post treatment plasticity index and linear shrinkage averages reduced by 80% and 60% respectively. The highest PI was 8.6% and the highest linear shrinkage was 5.4% (both resulting from PT3 which had 50% of the Pittsworth Alluvial in the basegrade blend).

6.2 Phase 3b Test Results: Slag/Lime General Blends

Figure 64 shows all UCS tests results for this testing phase against the three binder applications rates. As hypothesized, the general trend was an increase in UCS with an increase in application rate, regardless of the strength of the regression. The R squared value was expected to be low, as the UCS results were plotted against binder application rates for samples with variations in subgrade type and subgrade proportion.

39% of results were within the target strength range. The 5% application rate produced the highest level of complying results with 56% within the target range.

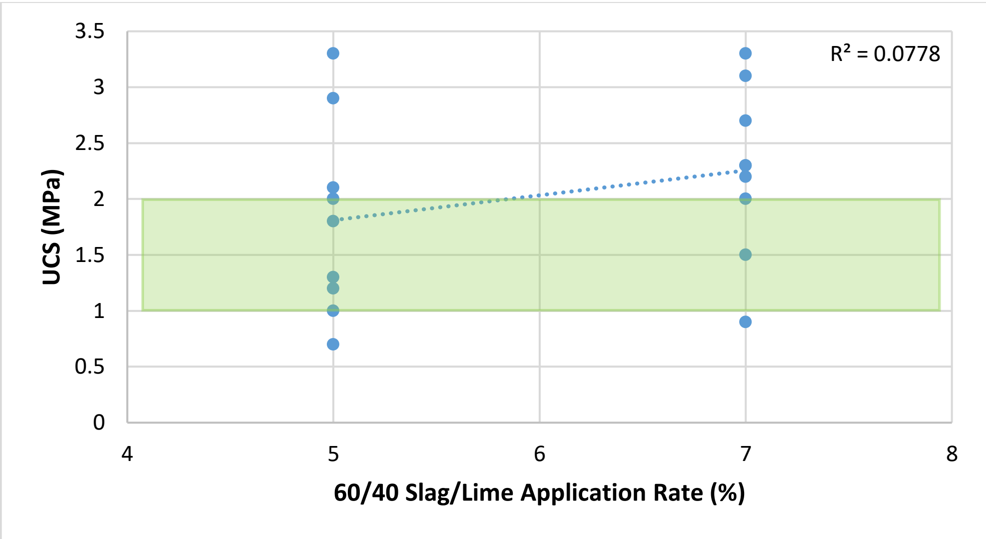


Figure 64. Phase 3b UCS v 60/40 Slag/Lime Application Rate

This data is explored in more detail in Figure 65 where the trends are displayed by subgrade type within the basegrade material.

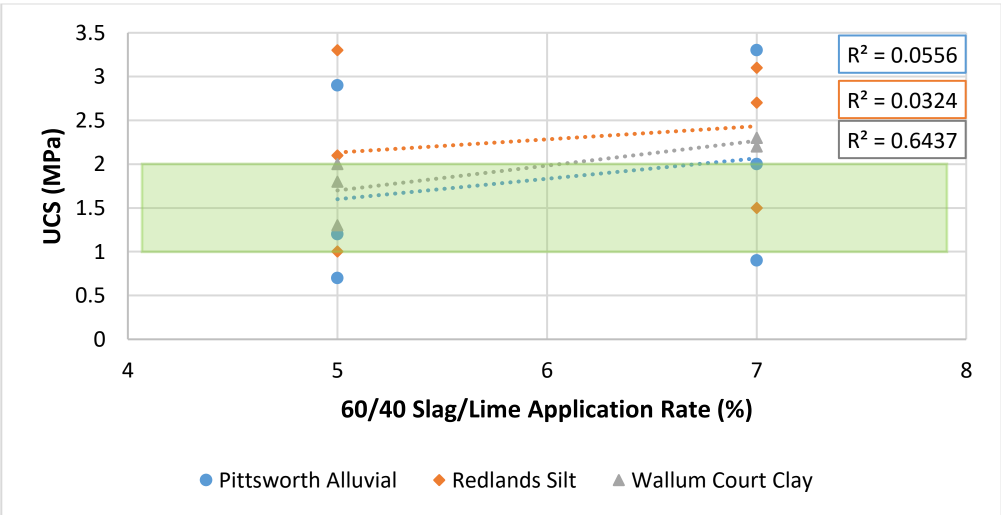


Figure 65. Phase 3b UCS v Subgrade Type

The UCS for each subgrade type within the basegrade mix increased at similar rates to each other with an increasing binder application rate (based on the slope of each trend line). The basegrade mix with Wallum Court Clay produced the highest level of compliance with 50% of results within the target range. The basegrade mix with Pittsworth Alluvial and Redlands Silt both produced 33% of results within the target range.

The average change in UCS regardless of subgrade type was approximately 0.25MPa for every 1% increase in binder application rate.

Figure 66 shows the UCS compared to the percentage of subgrade contained in the basegrade pavement.

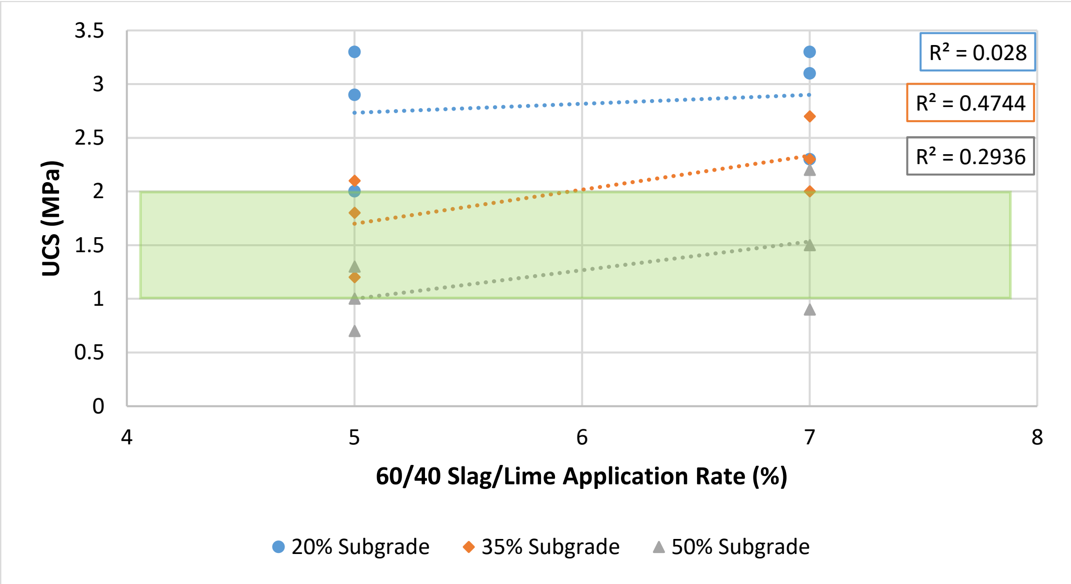


Figure 66. Phase 3b UCS v Subgrade Proportion

It is clear that the strength increases with increasing binder application rate, regardless of the percentage of subgrade. The pavement types with the highest level of compliance were those containing 35% and 50% subgrade materials. The range of UCS results for all pavement types containing 20% subgrade were between 2.0MPa and 3.3MPa. This indicates that a lower binder content (<5%) would be more likely to achieve the target strength range.

For every 15% increase in subgrade proportion, the UCS decreased by approximately 0.5-1.0MPa. This will be useful information when a trial mix design needs to be adjusted from any recommended application rates.

Figure 67 shows the UCS compared to the percentage passing the 0.075mm sieve of the untreated basegrade pavement types.

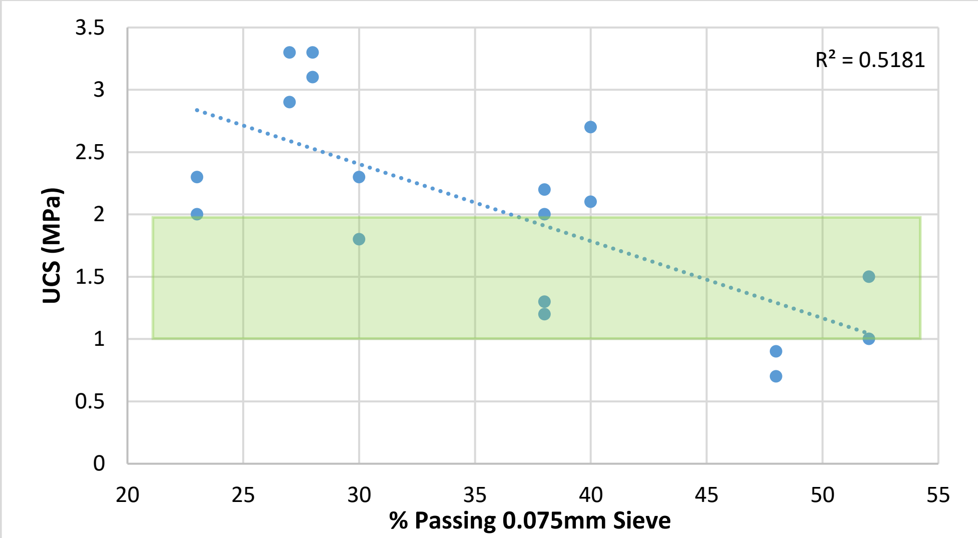


Figure 67. Phase 3b UCS v % Passing 0.075mm Sieve

The general trend shows a decrease in strength as the percent passing the 0.075mm sieve increases. The strength of this regression was considerably higher than for the same plot with the triple blend in testing phase 3a, even though this dependent variable does not consider other variables such as plasticity.

The majority of complying strengths occurred when the percent passing the 0.075mm sieve was between 35% and 55%. This data is explored in more detail in Figure 68 where the trends are displayed by binder application rate.

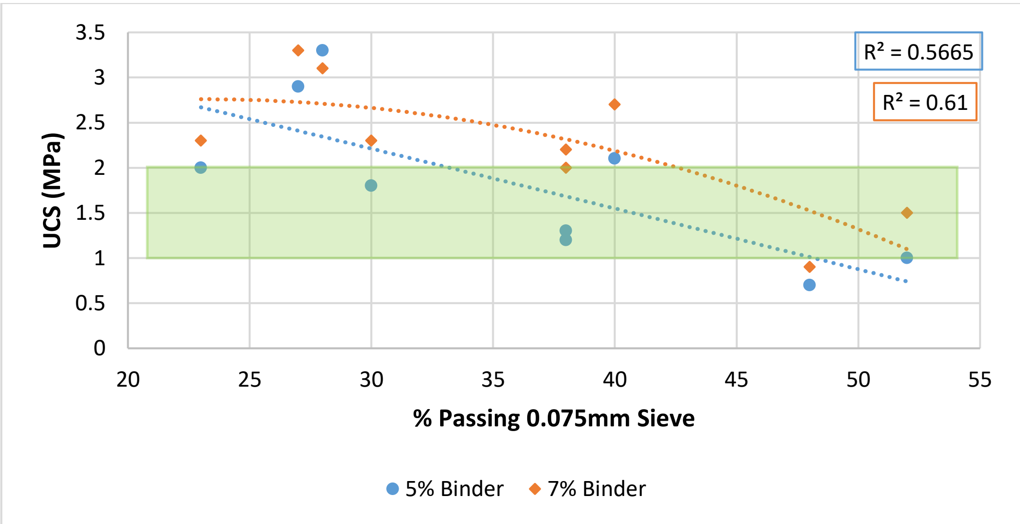


Figure 68. Phase 3b UCS v % Passing 0.075mm Sieve (by application rate)

Again the general trend was for a decrease in strength with an increasing fines content, regardless of the binder application rate. The majority of complying results occurred when the binder application rate was 5%. When the application rate was 7% and the percent passing the 0.075mm sieve was less than 35%, the majority of results exceeded the upper target strength of 2.0MPa. This aligns with expected outputs as the lower fines content reflects better quality materials, combined with higher binder content to increase the strength.

Figure 69 shows a similar graph but with UCS compared to the percent passing the 0.425mm sieve of the untreated basegrade pavement types. This was done to enable a further graph (shown in Figure 70) to be presented combining the effects of the 0.075mm and 0.425mm sieves, termed the fines ratio (TMR, 2020b).

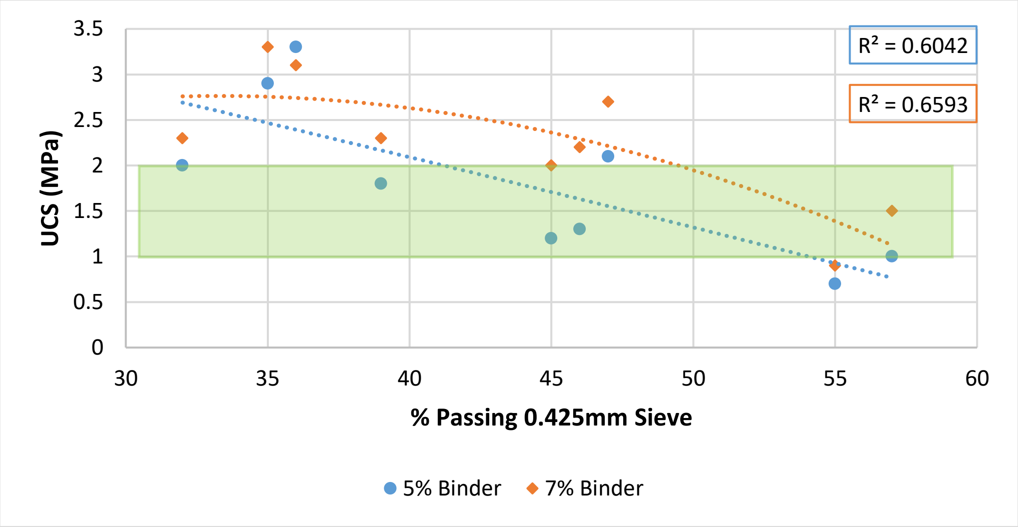


Figure 69. Phase 3b UCS v % Passing 0.425mm Sieve

The general trend shows a decrease in strength as the percent passing the 0.425mm sieve increases. The majority of complying strengths occurred when the percent passing the 0.425mm sieve was between 45% and 60%.

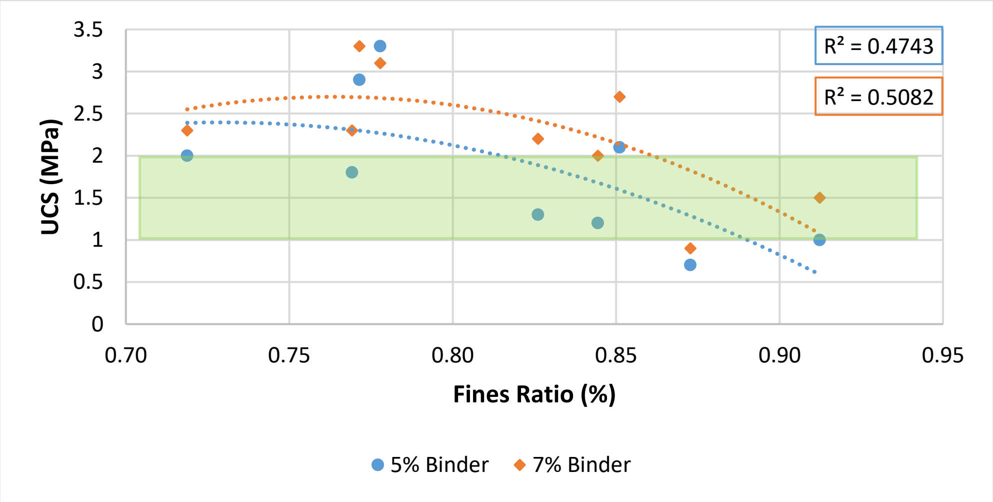


Figure 70. Phase 3b UCS v Fines Ratio

The general trend shows a decrease in strength as the fines ratio increases. The majority of complying strengths occurred when the fines ratio was between 0.80 and 0.95.

Figure 71 compares the plasticity index and linear shrinkage for the three pavement types tested in the untreated state and the treated state (ie. after the addition of the triple blend binder).

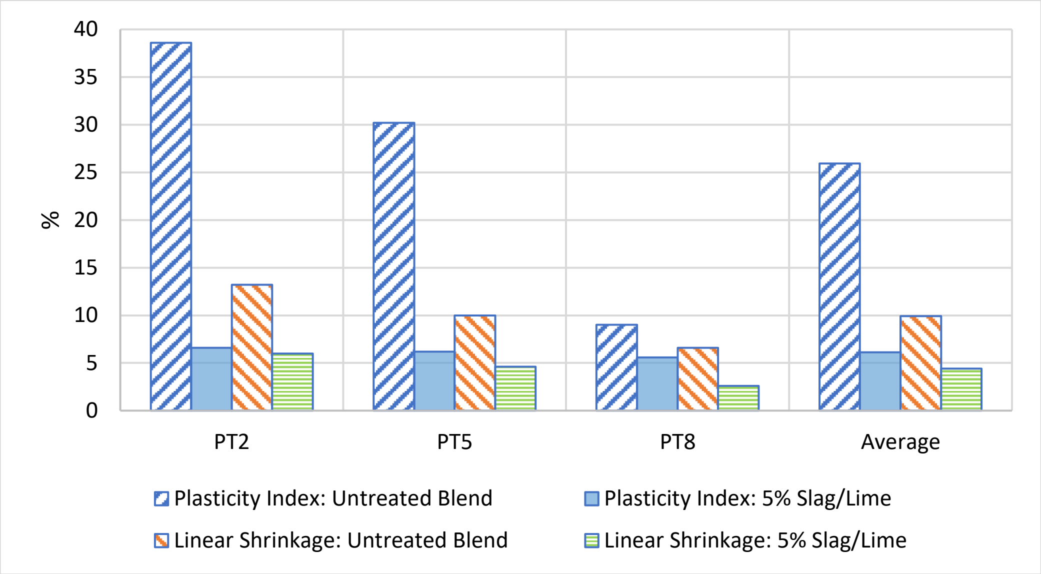


Figure 71. Phase 3b Plasticity Index & Linear Shrinkage: Pre and Post Treated Blends

The plasticity index and linear shrinkage of the untreated basegrade materials both showed a decreasing trend across the three subgrade types. This was expected as the same properties for the subgrade materials also followed that trend, with the Pittsworth Alluvial (in PT1-PT3) having the highest PI and LS and the Wallum Court Clay (in PT7-PT9) having the lowest PI and LS.

The post treatment plasticity index and linear shrinkage averages reduced by 76% and 56% respectively. The highest PI was 6.6% and the highest linear shrinkage was 6.0% (both resulting from PT2 which had 35% of the Pittsworth Alluvial in the basegrade blend).

6.3 Phase 4 Test Results: Lime Ameliorated Cement/Flyash General Blends

Figure 72 shows all UCS tests results for this testing phase against the three cement/flyash binder applications rates. As hypothesized, the general trend was an increase in UCS with an increase in application rate, regardless of the strength of the regression. The R squared value was expected to be low, as the UCS results were plotted against binder application rates for samples with variations in subgrade type and subgrade proportion.

67% of results were within the target strength range. With the lime pre-treatment being constant at 3%, addition of 3% 70/30 GB cement/flyash produced the highest level of complying results with 89% within the target range. The 2% GB trial produced 79% compliance whilst the 4% trial only produced 33% compliance. Most of the non complying results with 4% GB exceeded the 2MPa upper target.

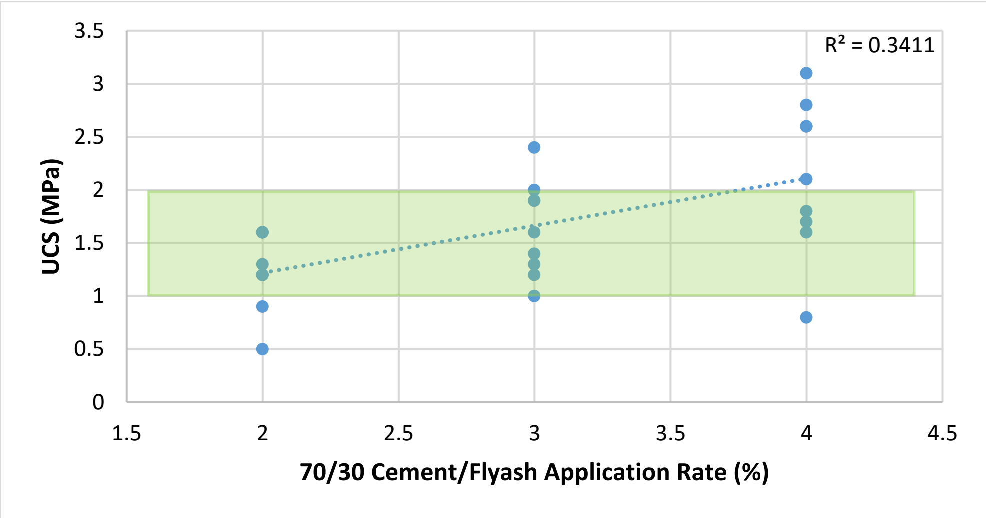


Figure 72. Phase 4 UCS v 70/30 Cement/Flyash Application Rate

This data is explored in more detail in Figure 73 where the trends are displayed by subgrade type within the basegrade material.

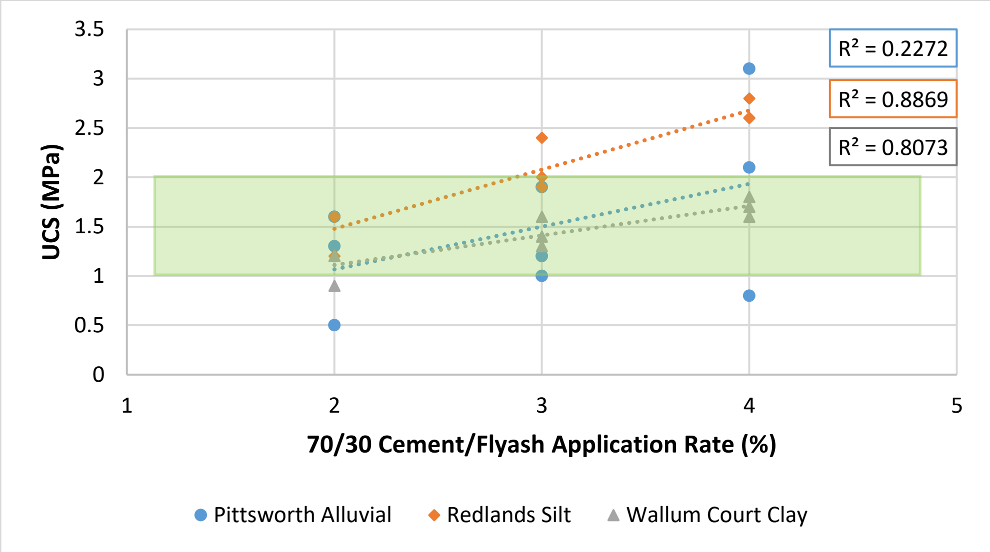


Figure 73. Phase 4 UCS v Subgrade Type

The UCS for each subgrade type within the basegrade mix increased at similar rates to each other with an increasing binder application rate (based on the slope of each trend line). The basegrade mix with Wallum Court Clay produced the highest level of compliance with 89% of results within the target range. The basegrade mix with Pittsworth Alluvial and Redlands Silt both produced 56% of results within the target range.

The average change in UCS regardless of subgrade type was approximately 0.5MPa for every 1% increase in binder application rate.

Figure 74 shows the UCS compared to the percentage of subgrade contained in the basegrade pavement.

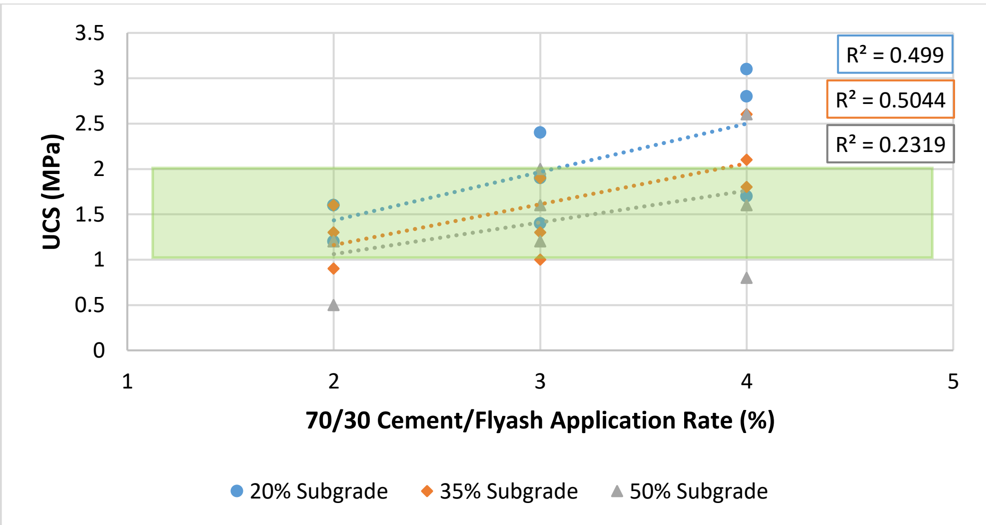


Figure 74. Phase 4 UCS v Subgrade Proportion

It is clear that the strength increases with increasing binder application rate, regardless of the percentage of subgrade. A 67% compliance rate was observed for pavement types with all three proportions of subgrade materials. This demonstrates a higher level of consistency over the binders trialled in test phases 3a and 3b, however that was expected due to the constant 3% lime pre-treatment which ameliorated the clay within each pavement type. Further, the GB application rates trialled were in increments of 1% compared to 2% in the other two test phases.

For every 15% increase in subgrade proportion, the UCS decreased by approximately 0.25-0.5MPa. This was a lower change in strength compared to the first two testing phases and assumed to be consistent with the effects of the lime pre-treatment that 'stabilised' the subgrade proportions prior to being strengthened with the GB. This will be useful information when a trial mix design needs to be adjusted from any recommended application rates.

Figure 75 shows the UCS compared to the percentage passing the 0.075mm sieve of the untreated basegrade pavement types.

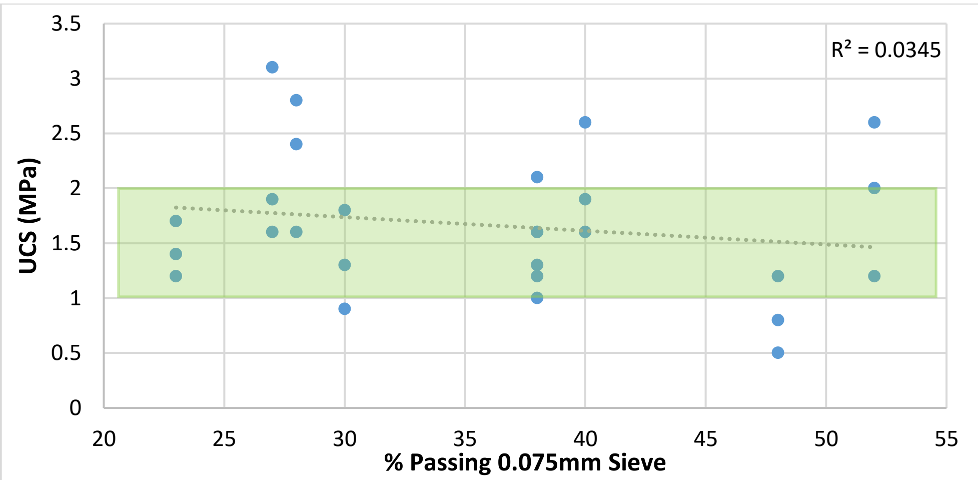


Figure 75. Phase 4 UCS v % Passing 0.075mm Sieve

The general trend shows a decrease in strength as the percent passing the 0.075mm sieve increases, although the reliability of the trend is poor. As stated for the previous two testing phases, this is likely to be a result of this variable not considering the effects of plasticity or other variables that can change strength results for a material with the same percent passing the 0.075mm sieve.

The majority of complying strengths occurred when the percent passing the 0.075mm sieve was between 20% and 40%. This data is explored in more detail in Figure 76 where the trends are displayed by binder application rate.

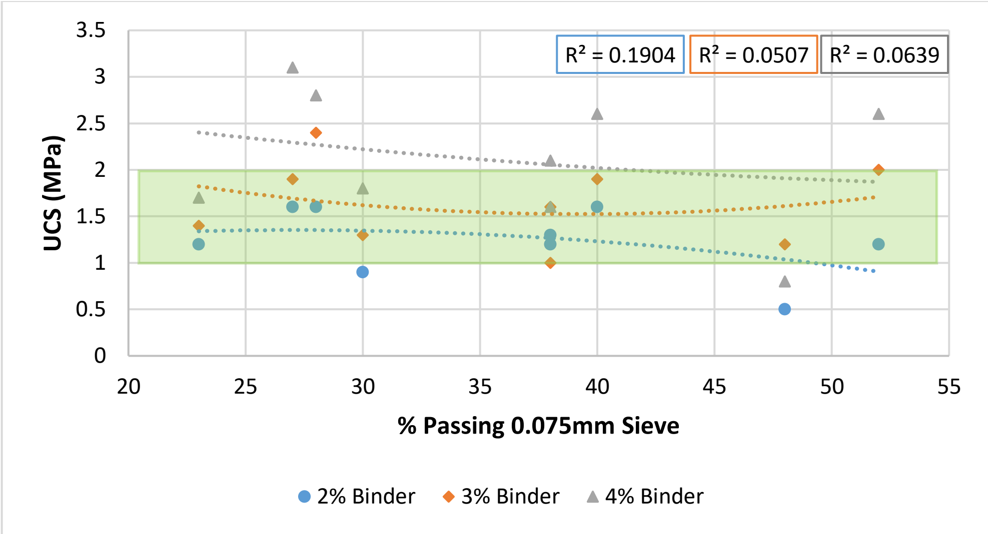


Figure 76. Phase 4 UCS v % Passing 0.075mm Sieve (by application rate)

Again the general trend was for a decrease in strength with an increasing fines content, regardless of the binder application rate. The majority of complying results occurred when the GB binder application rate was 2% and 3%.

Figure 77 shows a similar graph but with UCS compared to the percent passing the 0.425mm sieve of the untreated basegrade pavement types. This was done to enable a further graph (shown in Figure 78) to be presented combining the effects of the 0.075mm and 0.425mm sieves, termed the fines ratio (TMR, 2020b).

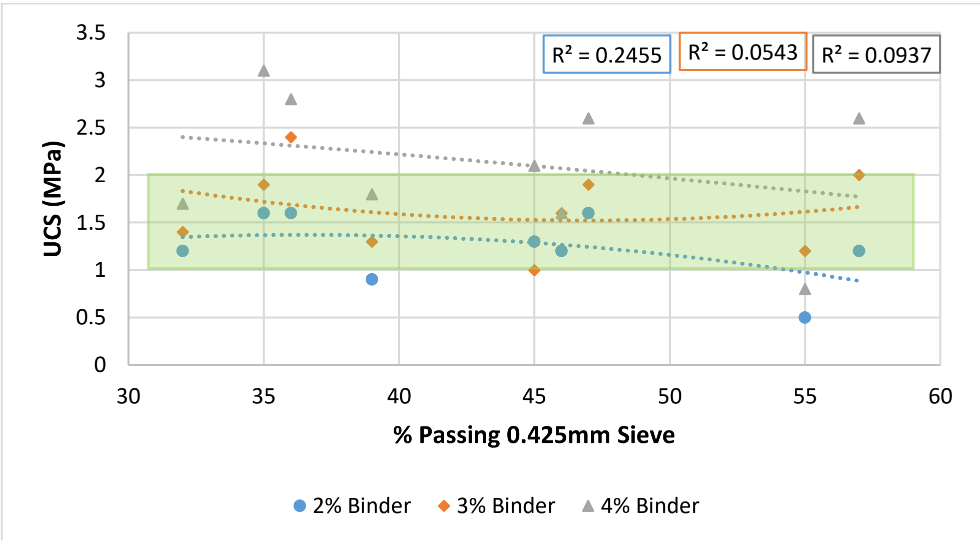


Figure 77. Phase 4 UCS v % Passing 0.425mm Sieve

The general trend shows a decrease in strength as the percent passing the 0.425mm sieve increases. The majority of complying strengths occurred when the percent passing the 0.425mm sieve was between 30% and 50%.

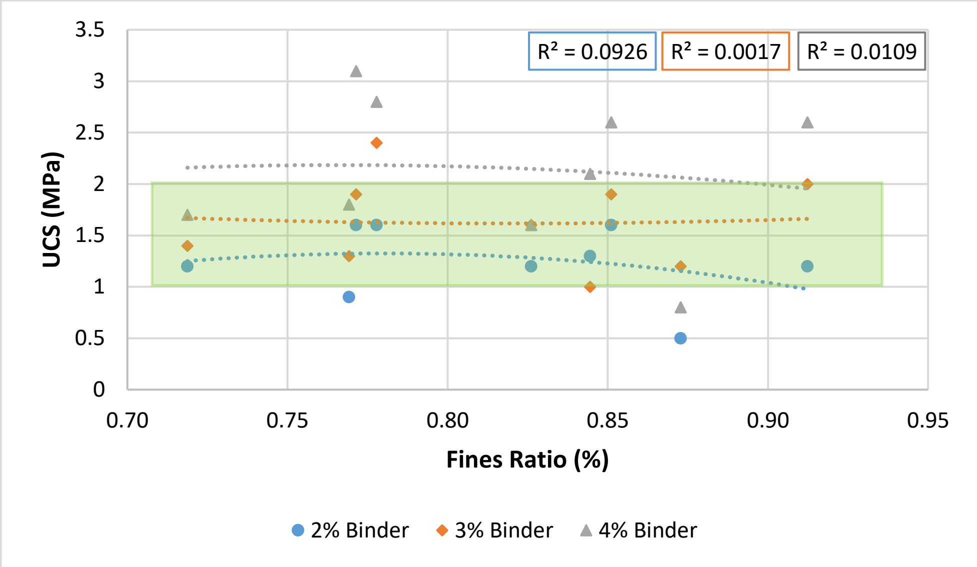


Figure 78. Phase 4 UCS v Fines Ratio

The general trend shows a decrease in strength as the fines ratio increases. The majority of complying strengths occurred when the fines ratio was between 0.70 and 0.85.

Figure 79 compares the plasticity index and linear shrinkage for the three pavement types comprising 35% subgrade, tested in the untreated state and the treated state (ie. after the addition of the triple blend binder). Results are displayed for the three GB application rates of 2%, 3% and 4%.

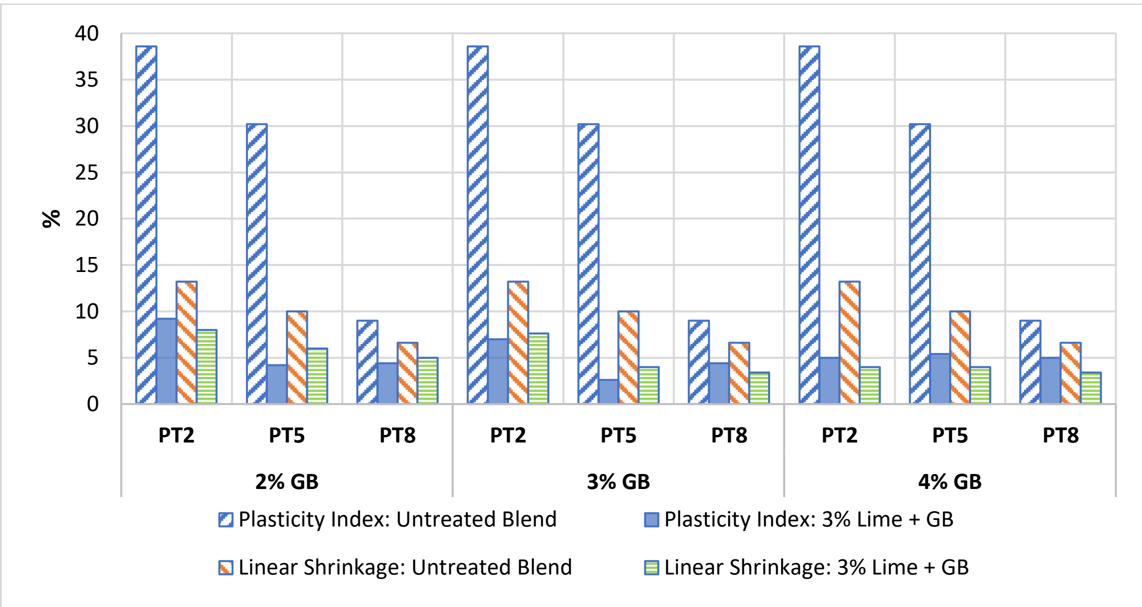


Figure 79. Phase 4 Plasticity Index & Linear Shrinkage: Pre and Post Treated Blends

The plasticity index and linear shrinkage of the untreated basegrade materials both showed a decreasing trend across the three subgrade types. This was expected as the same properties for the subgrade materials also followed that trend, with the Pittsworth Alluvial (in PT1-PT3) having the highest PI and LS and the Wallum Court Clay (in PT7-PT9) having the lowest PI and LS.

The post treatment plasticity index and linear shrinkage averages reduced by 80% and 49% respectively. The highest PI was 9.2% and the highest linear shrinkage was 8.0% (both resulting from PT2 which had 35% of the Pittsworth Alluvial in the basegrade blend).

6.4 Evaluation of Test Results from All Testing Phases Combined

All UCS test results have been reproduced below in Table 39. Those complying with the target 1-2MPa strength for lightly bound materials are shaded green.

Table 39. Summary of all UCS Results (MPa)

Averages	1.5			2.0			1.5				
	2.3	1.4	0.8	2.5	2.0	1.5	1.6	1.6	1.5		
	PT1	**PT2**	**PT3**	**PT4**	**PT5**	**PT6**	**PT7**	**PT8**	**PT9**	Averages	
3% Triple Blend	1.5	0.6	0.3	1.9	1.1	0.6	0.8	1.0	1.0	1.0	1.5
5% Triple Blend	1.8	1.5	0.6	2.0	1.9	1.6	1.3	1.5	1.3	1.5	
7% Triple Blend	2.3	1.7	1.3	3.1	1.9	1.3	1.8	2.0	1.8	1.9	
5% 60/40 Slag/Lime	2.9	1.2	0.7	3.3	2.1	1.0	2.0	1.8	1.3	1.8	2.0
7% 60/40 Slag/Lime	3.3	2.0	0.9	3.1	2.7	1.5	2.3	2.3	2.2	2.3	
3% Lime + 2% 70/30 GB	1.6	1.3	0.5	1.6	1.6	1.2	1.2	0.9	1.2	1.2	1.7
3% Lime + 3% 70/30 GB	1.9	1	1.2	2.4	1.9	2	1.4	1.3	1.6	1.6	
3% Lime + 4% 70/30 GB	3.1	2.1	0.8	2.8	2.6	2.6	1.7	1.8	1.6	2.1	
Subgrade %	20	35	50	20	35	50	20	35	50		

Overall 63% of the UCS results complied with the target strength range with 24% of the results exceeding the 2MPa upper limit. Figure 80 shows these results plotted against the binder application rate (note that the 3% lime ameliorated samples are reported by their respective 70/30 cement flyash application rates).

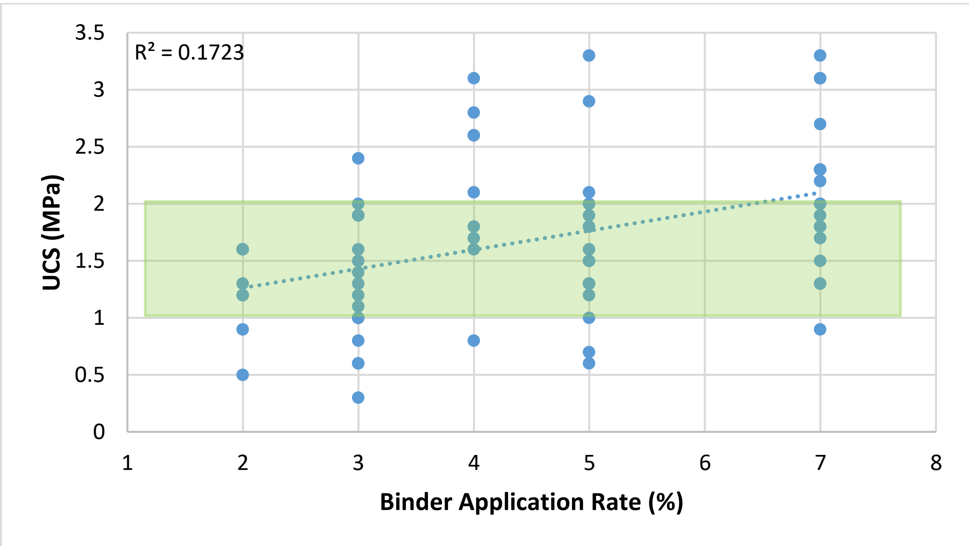


Figure 80. UCS v Binder Application Rate (all 72 trials)

As was found in the individual test phases, the overall trend shows an increasing UCS with an increase in binder content, which aligns with the original hypothesis. The R squared value was expected to be low as was the case for the individual test phases, as the UCS results were plotted against binder application rates for samples with variations in subgrade type and subgrade proportion.

A review of these results plotted against the linear shrinkage of the untreated pavement types and categorised by subgrade proportion is illustrated in Figure 81.

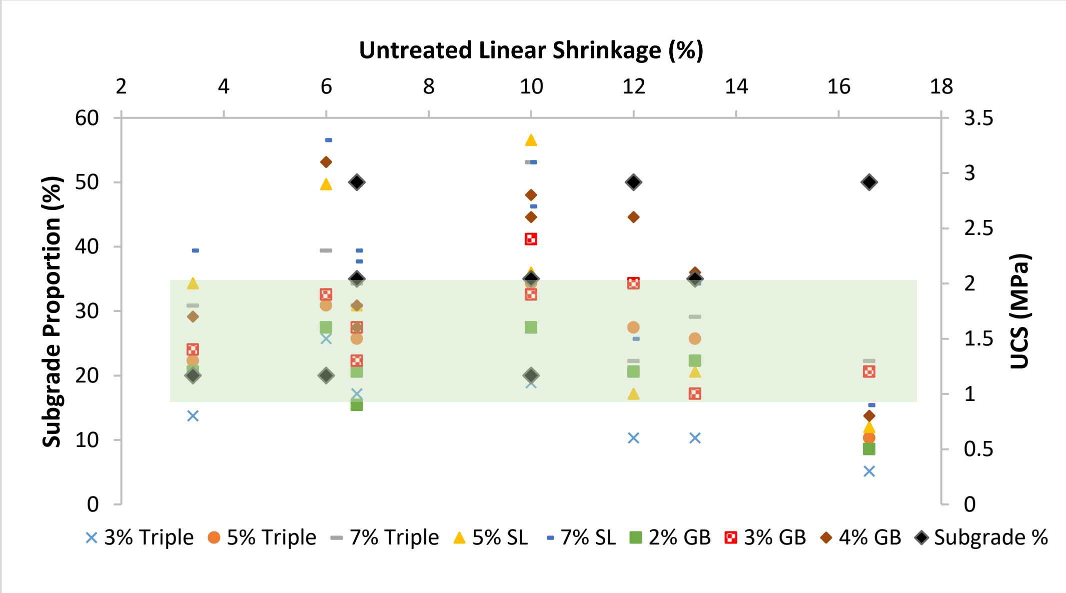


Figure 81. UCS v Untreated Material Linear Shrinkage (all 72 trials)

This chart shows that with an upper limit of 14% for linear shrinkage, almost all results exceed 1MPa, regardless of the binder type, binder application rate or subgrade proportion in the pavement type. For those results higher than 2MPa, reduced binder application rates can control this effect. Linear shrinkage is a good dependent variable for potential inclusion in the mix design protocol due to the ease of conducting this test. Figure 82 shows a similar plot with UCS against plasticity index of the untreated pavement types.

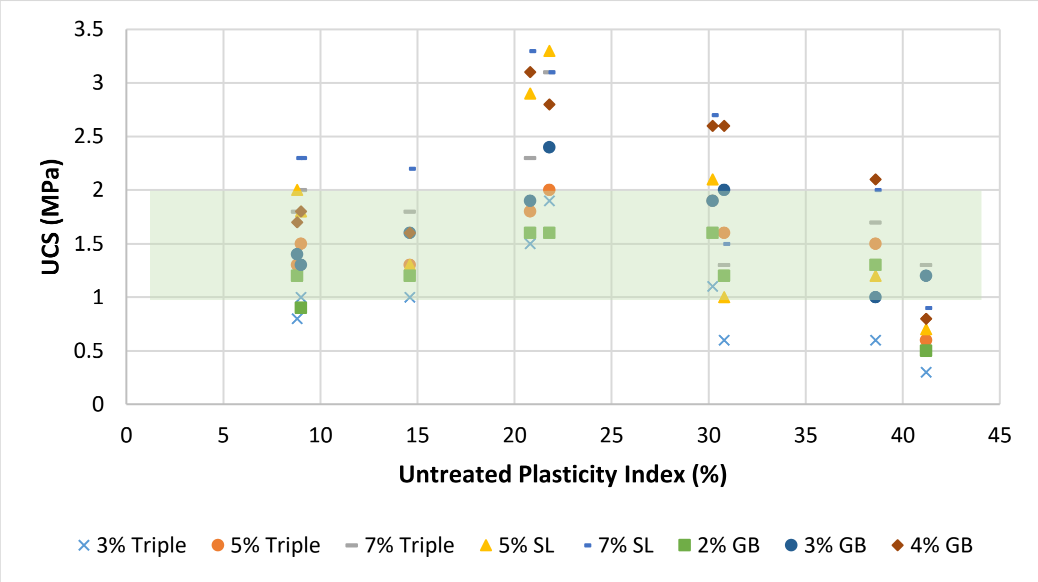


Figure 82. UCS v Untreated Material Plasticity Index (all 72 trials)

The general trend with plasticity index versus the UCS target range is similar to the linear shrinkage, whereby UCS results exceeded 1MPa until the PI exceeded 40%. Plasticity index will be another good dependent variable for potential inclusion in the mix design protocol based on relative ease of conducting this test and the high proportion of results that exceeded the lower strength limit.

Figure 83 shows a strong correlation between the linear shrinkage and plasticity index of the untreated pavement types. Taking the upper limit of 14% for linear shrinkage, this implies an upper limit of approximately 40% for plasticity index. This compares well with Figure 82 where the majority of UCS results with a plasticity index above 40% were below 1MPa. It is therefore concluded that either the plasticity index or the linear shrinkage of the untreated basegrade materials can be used as a defining dependent variable in the proposed mix design procedure.

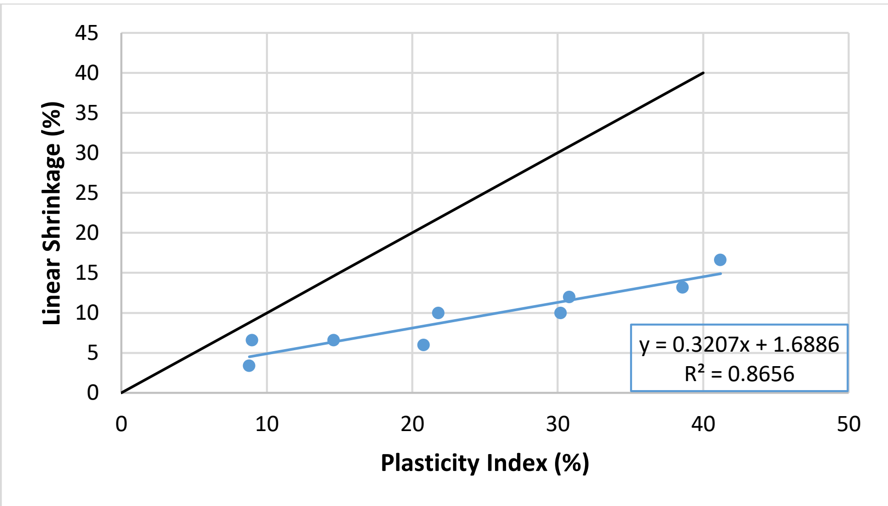


Figure 83. Plasticity Index v Linear Shrinkage: Untreated Pavement Types (all 72 trials)

Figure 84 shows UCS against the lime content within all of the binder blends. There does not appear to be any strong trends, hence this criteria is not expected to form part of the mix design protocol.

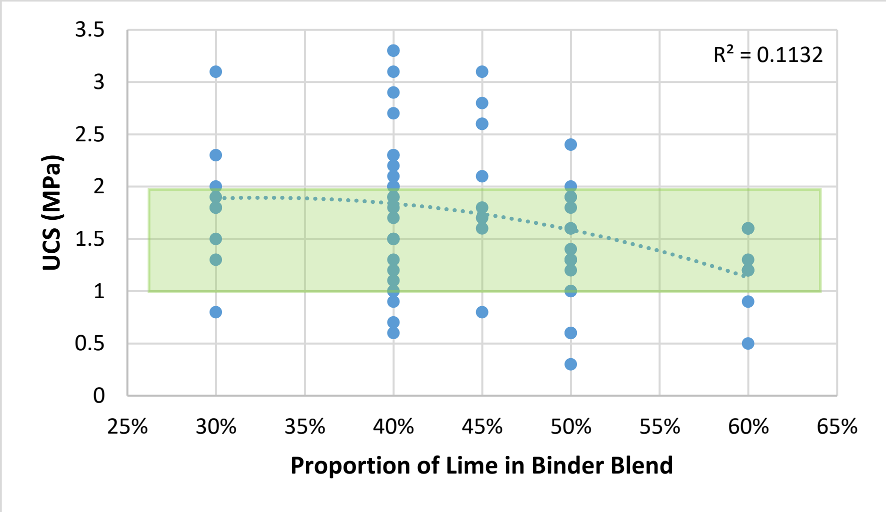


Figure 84. UCS v Lime Content in Binder Blend (all 72 trials)

Figure 85 and Figure 86 focus on the UCS obtained as a function of the subgrade incorporated into the pavement. Figure 85 shows the effect of the three subgrade types, while Figure 86 shows the effect of the amount of subgrade in the basegrade pavement.

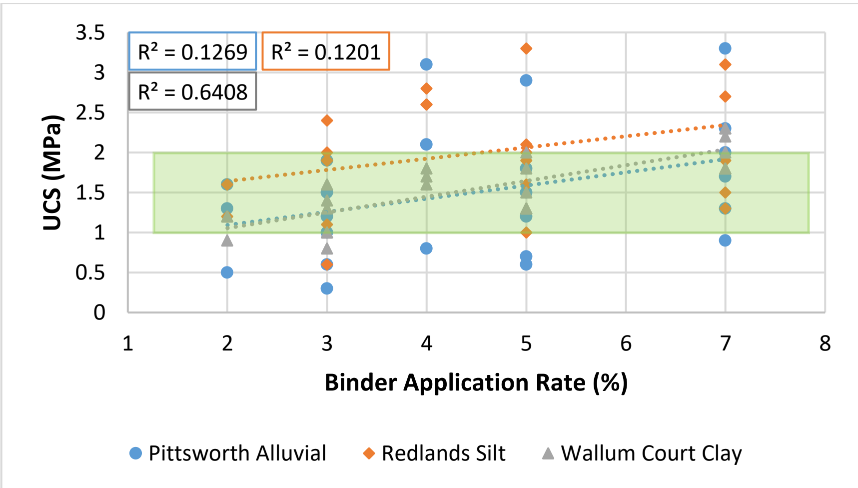


Figure 85. UCS v Subgrade Type (all 72 trials)

Although there is a wide spread of data inside and outside the target strength envelope, the UCS results for pavement types with each subgrade appear to be effected consistently by changes to the binder application rate (based on the similar slopes of the trend lines). The subgrade type however does not represent a variable to form part of the mix design protocol due to the high variability in results.

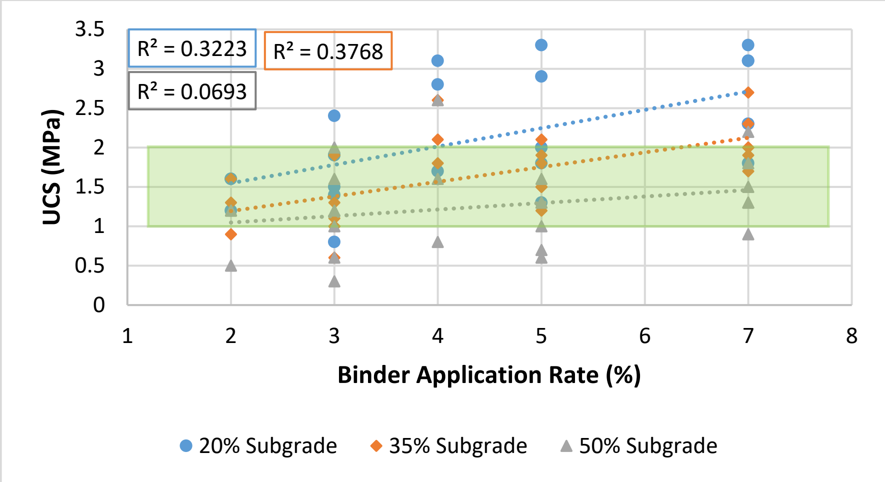


Figure 86. UCS v Subgrade Proportion (all 72 trials)

Figure 87 shows the UCS compared to the percentage passing the 0.075mm sieve of the untreated basegrade pavement types. The general trend shows a decrease in strength as the percent passing the 0.075mm sieve increases, although the reliability of the trend is poor. The majority of strengths complied with or exceeded the target strength range with the exception of the percent passing the 0.075mm sieve at 48%. The reason for this was not able to be explained.

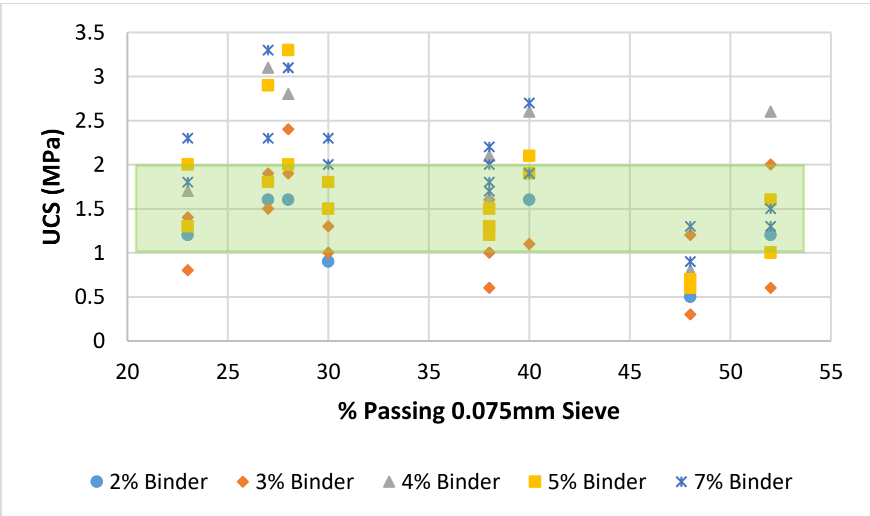


Figure 87. UCS v % Passing 0.075mm Sieve (all 72 trials)

Figure 87 shows a similar graph but with UCS compared to the percent passing the 0.425mm sieve of the untreated basegrade pavement types. This was done to enable a further graph (shown in Figure 88) to be presented combining the effects of the 0.075mm and 0.425mm sieves, termed the fines ratio (TMR, 2020b).

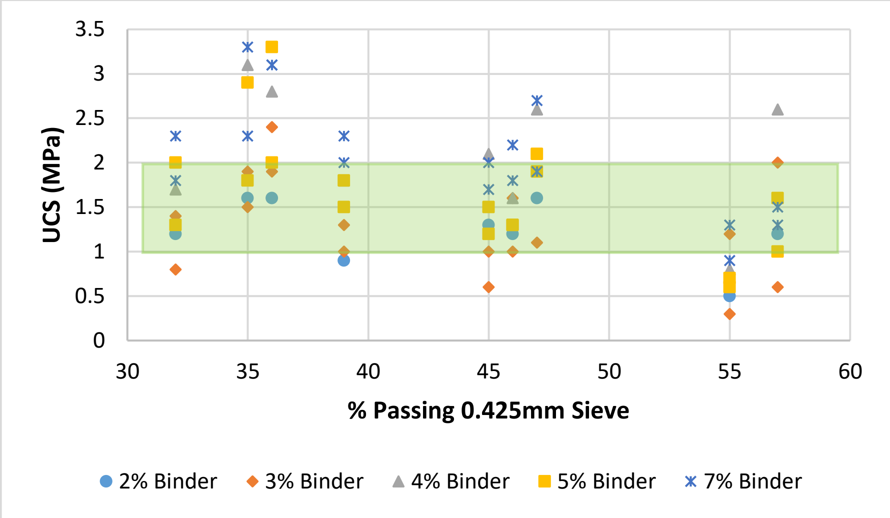


Figure 88. UCS v % Passing 0.425mm Sieve

The general trend shows a decrease in strength as the percent passing the 0.425mm sieve increases. The majority of strengths complied with or exceeded the target strength range with the exception of the percent passing the 0.425mm sieve at 55%. The reason for this was not able to be explained.

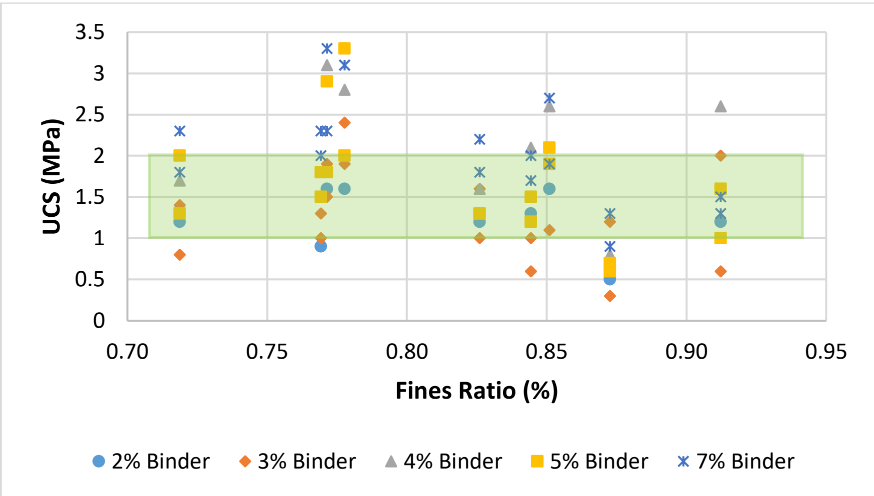


Figure 89. UCS v Fines Ratio

The general trend in Figure 89 shows a decrease in strength as the fines ratio increases. The majority of complying strengths occurred when the fines ratio was between 0.80 and 0.85.

Figure 90 and Figure 91 illustrate the linear shrinkage and plasticity index of the nine treated pavement types.

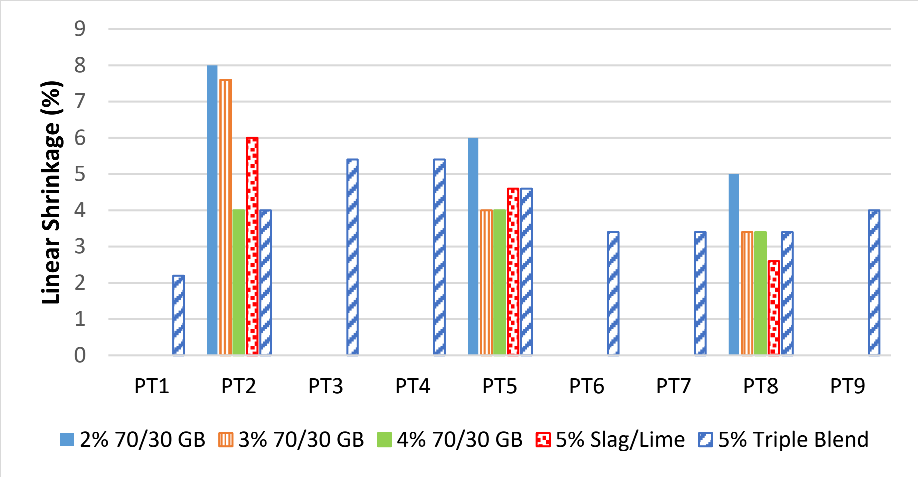


Figure 90. Linear Shrinkage: Treated Materials

The post treatment linear shrinkage average was 4.5% which was a reduction of 52% from the untreated pavement types. The 10^{th}-90^{th} percentile range was between 2.6% and 6.4%.

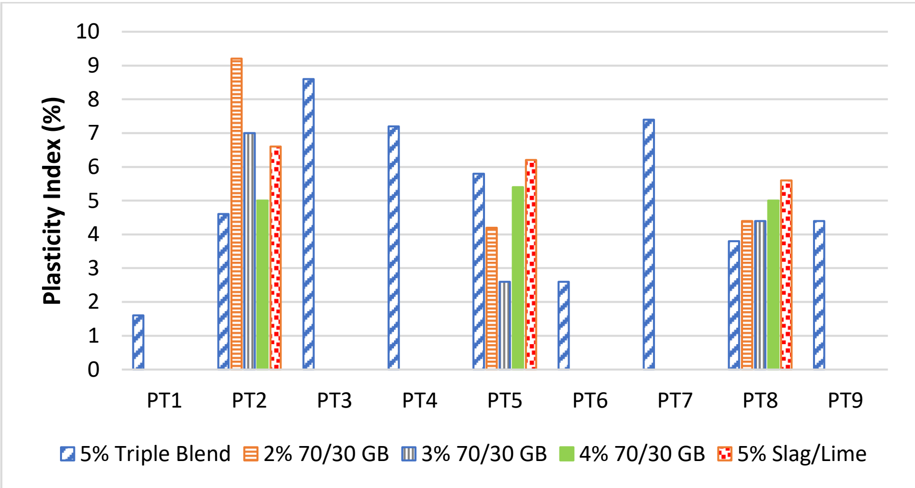


Figure 91. Plasticity Index: Treated Materials

The post treatment plasticity index average was 5.3% with the 10^{th}-90^{th} percentile range between 2.8% and 7.8%. This average was a reduction of 78% from the untreated pavement types.

Figure 92 shows the same linear shrinkage and plasticity index reductions post treatment, but illustrated as weighted values where they are multiplied by the percentage of material passing the 0.425mm sieve (Austroads, 2019a). Upper limits for weighted PI and weight LS of 500 and 300 respectively can be appointed from the research results. With the highest outlier result removed from Test Phase 3a, these upper limits are reduced to 300 and 270. An example upper limit of weighted plasticity index for an unbound basecourse and subbase material is 200 and 400 respectively (Austroads, 2019a). Therefore a direct comparison using these weighted values between a stabilised material and an unbound material is not straight forward. However it is worth noting the potential impact on adhesion of bituminous wearing courses when the weighted plasticity index exceeds the WPI and further work should be undertaken to examine this.

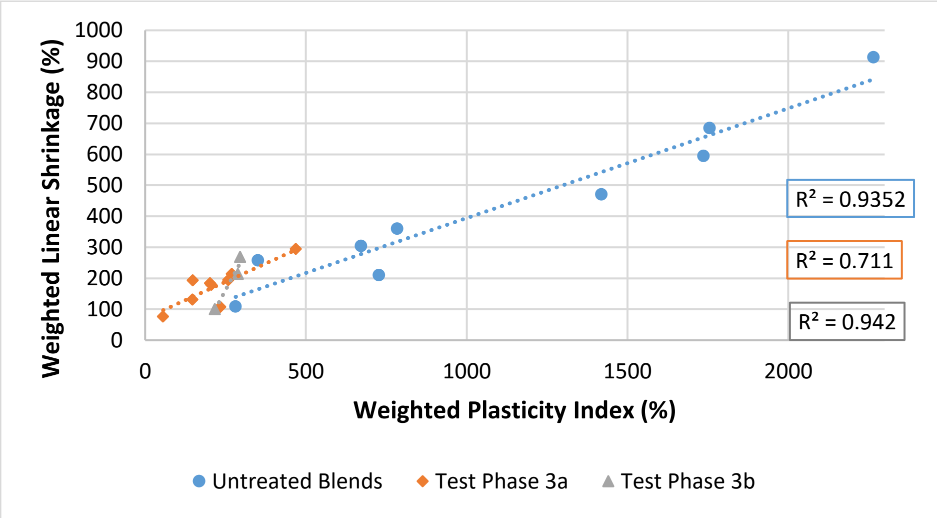


Figure 92. WPI v WLS: Test Phase 3a and 3b

Figures 93 to 95 show the results for the pavement types comparing UCS with the different binder types used. The common binder compared on the x-axis in each graph was the lime/cement/flyash triple blends, at application rates of 5% and 7%. These were compared against the 60/40 slag/lime at 5% and 7% as well as the lime ameliorated 70/30 cement/flyash at 3%.

Initial review of the three graphs suggest that most cases reveal higher strengths with the slag/lime and lime ameliorated cement/flyash blends compared to the lime/cement/flyash triple blends. However some exceptions without any clear trend were observed with the variations in strength between binders considered insignificant.

When the basegrade material was pre-treated with lime, the most significant effect was improvement to the strengths with 50% subgrade material in the pavement.

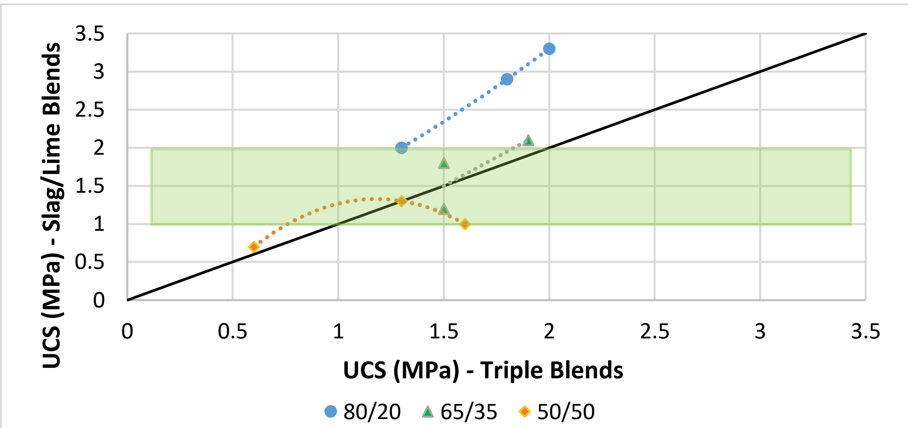


Figure 93. UCS Comparison: 5% Triple Blends v 5% Slag/Lime Blends

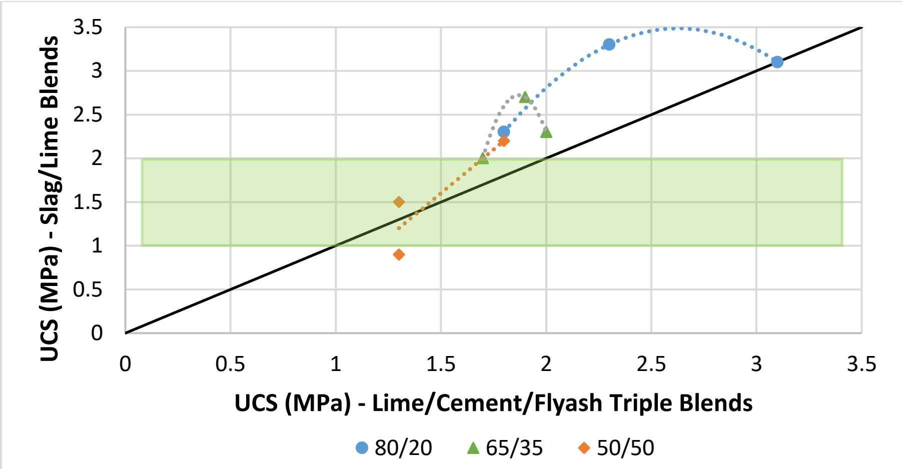


Figure 94. UCS Comparison: 7% Triple Blends v 7% Slag/Lime Blends

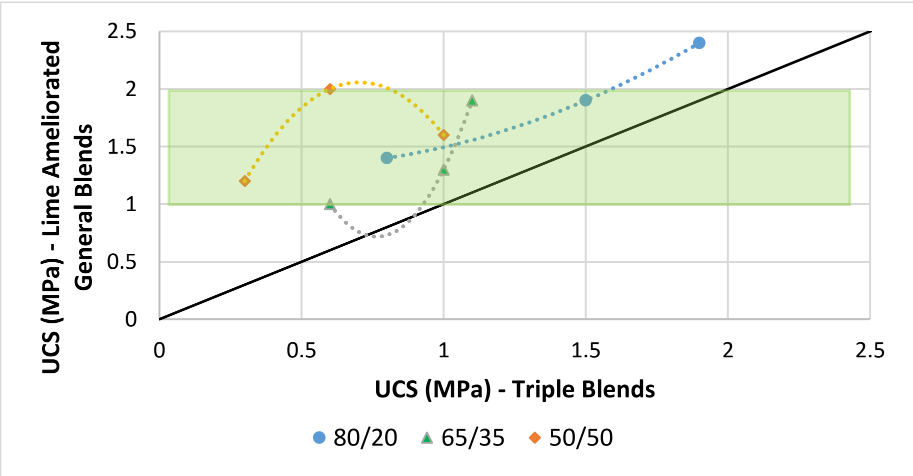


Figure 95. UCS Comparison: 3% Triple Blends v 3% Lime Ameliorated General Blends

A summary of Section 5 (Experimental Results) and Section 6 (Discussion of Results) has been provided in Section 7 (Development of Mix Design Procedures).

7 MIX DESIGN PROCEDURE

7.1 General

An indicative mix design procedure for basegrade stabilisation has been developed based on the results of the experimental research. The procedure has been summarised into a flowchart (Figure 96) that enables users to assess existing material properties within a pavement, inclusive of the granular pavement and subgrade materials and be offered a number of trial mix designs with nominated binder type and application rates to trial in the laboratory.

A summary of the results presented and discussed in the previous two sections are outlined in Table 40 where conformance with the target UCS range was the underlying variable.

Table 40. Summary of Experimental Results

Variable / Criteria	Phase 3a	Phase 3b	Phase 4	All Phases
UCS results within 1-2MPa	74%	39%	67%	**63%**
Most conforming binder application rate	5%	5%	3%+2%	**5%**
Pittsworth Alluvial subgrade conformance	56%	33%	56%	**50%**
Redlands Silt subgrade conformance	89%	33%	56%	**58%**
Wallum Court Clay subgrade compliance	89%	50%	89%	**79%**
Most conforming percentage of subgrade[1]	20-50%	35-50%	20-50%	**35%**
Most conforming 0.075mm sieve	20-40%	35-55%	20-40%	**20-40%**
Most conforming 0.425mm sieve	30-50%	45-60%	30-50%	**30-50%**
Most conforming fines ratio	0.70-0.85	0.80-0.95	0.70-0.85	**0.70-0.85**
Most conforming plasticity index (untreated)				**N/A**
Most conforming linear shrinkage (untreated)				**< 14%**
10^{th}-90^{th} percentile plasticity index post treatment				**2.8-7.8%**
Plasticity index reduction post treatment	80%	76%	80%	**78%**
10^{th}-90^{th} percentile linear shrinkage post treatment				**2.6-6.4%**
Linear shrinkage reduction post treatment	60%	56%	49%	**52%**
Average +/- UCS with +/- 1% binder[2]	0.25MPa	0.25MPa	0.5MPa	**0.25-0.5MPa**
Average +/- UCS with +/- 15% subgrade[3]	0.4MPa	0.5-1.0MPa	0.25-0.5MPa	**0.5MPa**

Notes:

1. *'Most conforming' allows for UCS results that exceeded 2MPa.*
2. *A 1% change refers to an absolute change (eg. from an application rate of 5% to 6%).*
3. *A 15% change refers to an absolute change (eg. from 20% subgrade to 35% subgrade to 50% subgrade).*

7.2 Development of Mix Design Procedure

With adequate information available, the mix design procedure for basegrade stabilisation was able to be developed, based on the results displayed in Table 40, the detailed experimental results analysis in Section 6 and the literature review which provided multiple examples of mix design procedures (AustStab, 2020; Austroads, 2002; Austroads, 2019a; Brisbane City Council, 2011; Jones, circa 1998; Little, 1995; Little, 2009; Opus International Consultants Limited, 2017; US Army Corps, 1984; Wilmot, 1994). The latter comprised various formats from flowcharts, to text based prescriptions through to tables. Common elements with many of them included provisions for evaluation of particle size distribution and Atterberg Limits of the untreated material.

For this new procedure, it was proposed to utilise both of these parameters, specifically the % passing the 0.075mm sieve, the linear shrinkage and the plasticity index. The latter two are alternative options due to being statistically significant, but they are not mutually dependent from a testing perspective.

The other key variable that was useful in this research was the percentage of subgrade in the basegrade pavement type. It provided a variety of strength results with changing subgrade proportions, regardless of the type of subgrade being used. It was therefore able to provide valuable assistance along with the linear shrinkage and plasticity index which both captured the variations of material quality based on subgrade type.

Indicative limits for these parameters that have been assigned to the mix design procedure are:

% passing the 0.075mm sieve	25% - 55%
Linear shrinkage	< 14%
Plasticity Index	10% - 40%
Proportion of subgrade	< 30% & 30 - 50%

Although the most conforming range of UCS results for the percentage passing the 0.075mm sieve was 20-40%, 56% of the results between 40-55% passing were within the target strength range (one outlier was 2.6MPa). Hence why the upper limit was set to 55%. The lower limit of 25% coincides with current published values for the percentage passing the 0.075mm sieve, being 25% (Austroads, 2019a).

The reason for segregating the proportion of subgrade was to provide variations in the suggested binder application rates within the mix design procedure which would ultimately optimise the UCS outcome for the target 1-2MPa, based on the experimental research results.

Figure 96 illustrates the indicative mix design procedure for basegrade stabilisation. Appendix H has a larger reproduction of this chart which provides greater clarity. The mix design procedure has three distinct phases, being:

1. A preliminary screening of the project to assess suitability for basegrade stabilisation, based on assessment of the existing pavement thickness versus the design thickness and the design traffic loading;

2. Evaluation of the basegrade material properties, specifically the fines (% passing the 0.075mm sieve), the linear shrinkage or the plasticity index and the proportion of subgrade within the mixture;

3. Selection of one or more of the available mix designs comprising recommended binder types and recommended binder application rates.

Laboratory testing to validate any trial mix design is always recommended. This procedure provides a starting point for the assessment of initial conditions and material properties and provides guidance on trial mix designs to optimise the target strength envelope of 1-2MPa.

Where trial mix designs do not result in the target strength, a number of options are provided to enable additional mix designs to be trialled, or to adopt a result based on graphical interpolation.

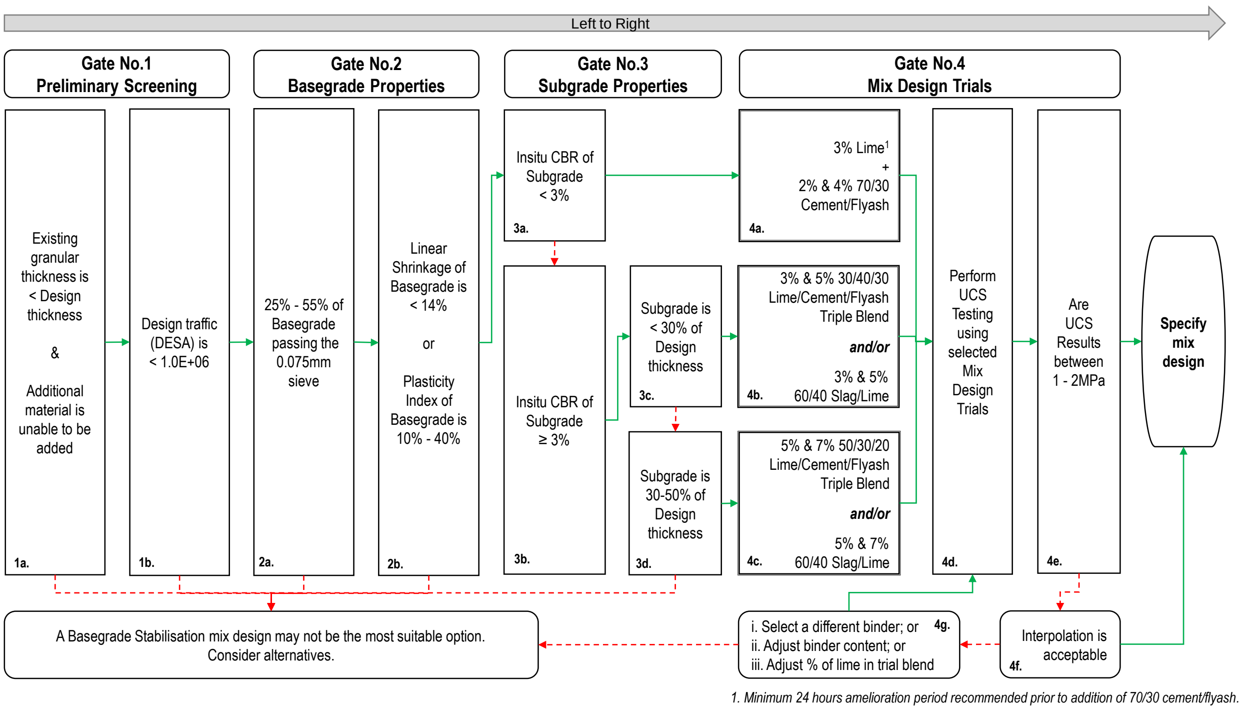


Figure 96. Indicative Basegrade Stabilisation Mix Design Procedure

7.3 Use of Design Chart

User notes to accompany the procedure illustrated in Figure 96 are detailed below. Unique alpha numeric identifiers shown in each box of the procedure align with these notes.

General Notes:

- Start on the left hand side and work towards the right hand side
- At any point in the chart, if the answer to a question is YES, follow the green solid line
- At any point in the chart, if the answer to a question is NO, follow the red dashed line

Specific Notes:

1a. Existing granular thickness can include bituminous wearing surface where no level restrictions exist. Additional material refers to a review of the opportunity to raise the level of the existing pavement with another suitable unbound material (eg. a granular overlay).

1b. Engineering judgement is required on a case by case basis to assess the heavy vehicle traffic spectrum for the site against the specific basegrade pavement being considered.

2a. The sieve analysis is for the combined pavement granular and subgrade material, ie. the basegrade mixture, prior to the addition of any stabilising binder/s.

2b. The linear shrinkage and plasticity index values are for the combined pavement granular and subgrade material, ie. the basegrade mixture, prior to the addition of any stabilising binder/s. Both variables do not need to comply together. If either the linear shrinkage or plasticity index variable is found to satisfy the respective assigned limits, progression to the next stage is permitted.

3a/3b. Insitu CBR usually refers to an estimate onsite during an investigation (eg. with a dynamic cone penetrometer, or back calculated from deflection data). This variable is only for the untreated subgrade.

3c/3d. This is the proportion of the subgrade as a percentage of the total basegrade thickness to be stabilised, eg. If the design thickness is 250mm and the existing pavement thickness is 150mm, the subgrade proportion represents 100mm of the total basegrade thickness, or 40%.

4a. For soft subgrades where the insitu CBR<3%, the suggested trial mix design is intended to be a two phase process where phase 1 is an initial lime pre-treatment to a thickness of at least 300mm. Phase 2 occurs after at least 24 hours of amelioration (usually the next shift) to the design thickness which is intended to be at least 50-100mm less than the initial lime pre-treatment thickness. This is to enable the phase 1 treatment to produce a subbase, or buffer between the cement/flyash treatment and the soft subgrade during phase 2. Binder type and application rates for phase 2 are based on optimisation from the research outcomes. Adjustments can be made based on local knowledge and/or experience.

4b/4c. Two binder types and two corresponding application rates are provided to trial. These are based on optimisation from the research outcomes. One or both mix designs can be trialled.

4d. UCS testing is recommended to be undertaken after 28 days of curing at ambient temperature in accordance with local government or state government jurisdiction test methods. Accelerated curing at raised temperatures to obtain results after 7 days may be undertaken in accordance where a test method exists (eg. Transport for NSW Test Method T131).

4e. Evaluation of a series of UCS results should be based on consideration of homogeneous lots, where the coefficient of variation does not exceed 30%. Typically the mean result from a series of UCS test results is evaluated against the target strength range of 1-2MPa. Outliers should be investigated further as they may skew the data set.

4f. Where UCS results are outside the target strength range of 1-2MPa, selection of a mix design application rate is permissible by interpolation from a plot of the results. Interpolation may not be considered suitable where all results are either below or above the target strength range (but not both). However forward or backward forecasting of trend lines with a moderate to strong coefficient of determination ($R^2 > 0.5$) may reveal adequate results.

4g. For option i. an adjustment to the binder type may produce different results (eg. the cement/flyash component of blends could be exchanged for a slag/cement.
For option ii. Adjustment of the binder application rate (%) may produce different results. A +/- 1% change in binder application rate may alter the UCS by +/- 0.25MPa to 0.5MPa.
For option iii. The lime content within the blends may be adjusted to produce different results (eg. 3% lime in the pre-treatment phase could be increased to 4%, or the 30/40/30 lime/cement/flyash triple blend could be adjusted to 40/40/20.

It is recommended that any adjustments to trial mix designs are done one at a time so that changes in results can be attributed to a single variable.

7.4 Recommended Basegrade Pavement Particle Size Distribution

In addition to the percentage passing the 0.075mm sieve being an integral part of the mix design procedure, a recommended particle size distribution envelope for basegrade pavements suitable for stabilisation has been developed (refer Table 41 and Figure 97). The purpose of this grading envelope is to clarify the limits and avoid confusion with the otherwise incorrect use of the multitude of other published grading limits, none of which relate to basegrade stabilisation pavements.

Table 41. Proposed Grading Limits for Basegrade Stabilisation

Particle Size Distribution (mm)	Proposed Upper Limit	Proposed Lower Limit
26.5	100	100
19	100	80
9.5	90	60
4.75	80	45
2.36	72	37
0.425	60	28
0.075	55	25

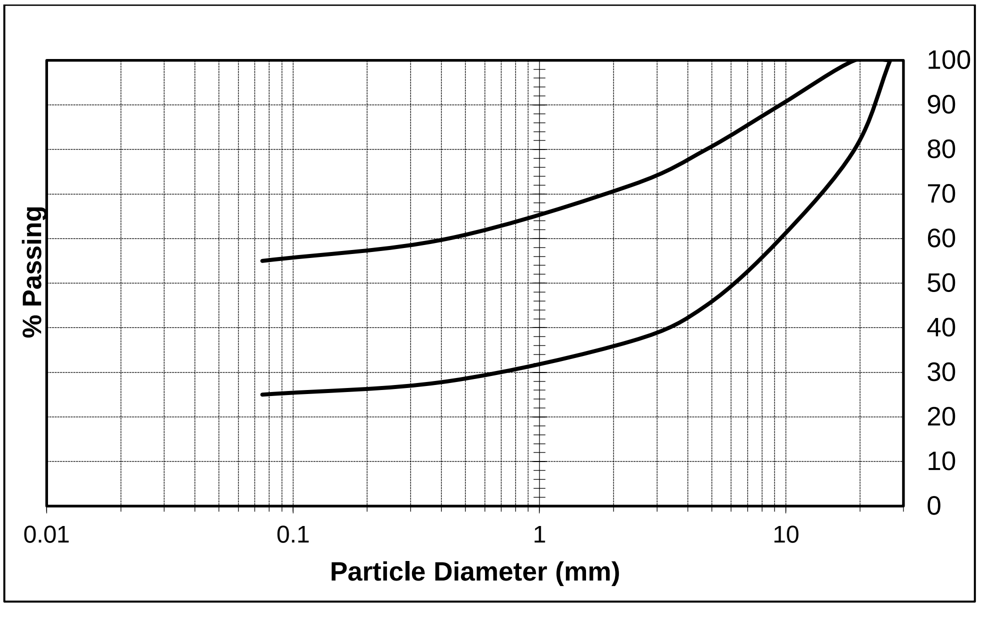


Figure 97. Proposed Grading Limits for Basegrade Stabilisation

8 APPLICATIONS IN LOCAL GOVERNMENT

Implementation of the basegrade stabilisation mix design procedure as part of a local council asset management strategy will provide significant value to their commercial position and sustainability footprint. Wherever a basegrade stabilisation project is undertaken by a local council, previous experience is that the council returns a financial saving compared to the otherwise more expensive pavement rehabilitation alternatives (Goodsell, 2020; Larkan, 2020; Wilmot, 2020). Further, a basegrade stabilisation treatment recycles and reuses the existing pavement materials rather than disposing of the old pavement materials and exhausting finite virgin quarried products. This form of pavement recycling results in far less CO2 emissions and ultimately a lower carbon footprint (Young, 2014).

Although the current limitation for application of a basegrade stabilisation treatment is for lightly trafficked roads (DESA<1.0E+06), implementation should be at the discretion of the council engineer based on a risk assessment for the specific project being analysed. Other factors may preclude or permit a basegrade stabilisation project. The quantity and location of underground services beneath the existing surface are one example. Where encroaching underground services can be lowered, the cost of this preliminary activity must be taken into consideration during the project scoping and budgeting phase to ensure these risks are captured (Larkan, 2020).

In the mix design procedure shown in Figure 96, there are ten different mix design trials available. Apart from offering these to optimise the UCS strength with the least amount of binder, the variations in binder types is also aimed at allowing the use of basegrade stabilisation in as many local government areas of Australia as possible. Each state of Australia has access to different binders from different suppliers. Not all geographical locations in Australia can access the same products. For example, slag is not produced or regularly available in north Queensland or Tasmania. Similarly, triple blends that are pre-blended by the supplier are not available in all states. Where the individual constituents are available (a typical example is where hydrated lime can be sourced separately to a cement/flyash general blend), the lime can be spread and mixed separately to the cement/flyash blend in the field to achieve the same outcome as a pre-blended triple blend. It should however be noted that it is not recommended to spread and mix the cementitious blend constituents separately (ie. the cement and the flyash in the above example), as adverse reactions detrimental to the outcome have been observed (Wilmot, 2020).

From a quality control perspective, local government specifications for stabilisation are wide and varied in Australia. They range from highly detailed and specific to the individual council, to adoption of specifications prepared by others such as state road authorities or NATSPEC which is a not for profit organisation owned by government and industry (NATSPEC, 2020). Regardless of the specification source, one of the most important elements of any specification in achieving the desired strength that was achieved in the laboratory mix design testing, is the compaction quality, or density profile throughout the thickness of the treatment. Since a basegrade stabilisation treatment is ultimately requiring compaction of a stabilised layer directly on a subgrade, if that subgrade is weak at the time of construction, conforming density may be difficult to achieve. A number of strategies can be employed to reduce this risk.

Using the triple blends or slag/lime blends will have longer working times than the cement/flyash general blends applied after a lime pre-treatment. Therefore the triple blends and slag/lime blends give rise to increased opportunities for the construction teams to achieve the specified density targets (Bullen & Suciu, 1991).

Application of the triple blend in two phases, as an initial lime pre-treatment followed by the cementitious blend provides opportunities to further minimise this risk. The initial lime treatment can be specified to a depth that is at least 50-100mm greater than the design thickness. This will produce a subbase or buffer of material that has improved characteristics from the untreated subgrade for the cementitious treated layer when stabilised the following day. It is important to recognise with this approach that the initial lime pre-treatment should have density targets commensurate with the cementitious treatment the following day. This is to ensure that the ‘buffer’ is adequately compacted and does not facilitate future settlement in the form of rutting under traffic load. Compaction of the final layer can then occur with a higher degree of confidence.

Where a basegrade stabilisation treatment is being considered in local government, the coefficient of variation in material types and therefore quality of materials can often be high, as a result of multiple construction activities of varying consistency over the years. One method to increase the likelihood of success with a basegrade stabilisation project is with the initial material sampling phase as part of the geotechnical investigation. It is recommended that the frequency of testing be no less than 1 per 50 lineal metres. Trenching the full width of the pavement is considered an acceptable approach to identify variances in the transverse direction. Otherwise two to three test pits depending on the width of the site should be considered.

9 CONCLUSIONS AND RECOMMENDATIONS

Local Government's use of pavement recycling in Australia through insitu stabilisation commenced in the 1950's. Basegrade stabilisation as a specific road rehabilitation technique comprising a blend of existing granular materials and subgrade materials has been applied on Australian local government roads since the 1970's, although it has never been categorically defined until now. Further, published mix design procedures normally applied for basecourse or subgrade stabilisation are not suitable for basegrade stabilisation due to the distinct variances in material properties being assessed for treatment.

An indicative mix design procedure for basegrade stabilisation has been developed. The basis for its development was founded on an experimental research laboratory testing program. The UCS test was the primary test for strength assessment with various binder types and various binder application rates used. A target strength envelope of 1-2MPa after 28 days of ambient temperature curing was established, which aligns with the historical evidence for local government roads stabilised in Australia.

In order for the proposed mix design procedure to optimise selection of an appropriate binder and quantity of binder to meet the strength target, numerous variables were established within the experimental testing program. These included three different subgrade materials with properties ranging from 1.5% to 8% for soaked CBR, 3.4% to 21.4% for linear shrinkage, 0.3% to 1.9% for swell and 14.2% to 49.4% for plasticity index. Blended with a single base quality gravel at subgrade proportions of 20%, 35% and 50%, nine pavement types were generated for testing and examination. 72 UCS tests in total were conducted with 63% returning results in the 1-2MPa range, with only 14% falling below the 1MPa lower limit. The lowest result obtained was 0.3MPa and the highest result was 3.3MPa. These results enabled optimisation of the indicative mix design procedure due to the size of the data set and range of mix designs trialled.

The 60/40 slag/lime trials produced the highest strengths compared to the other binder trials at the same application rates, however all binder types produced sound results. Original hypotheses established in the research program were all confirmed. UCS increased as the binder application rate increased. UCS decreased as the proportion of subgrade increased. It also decreased as the quality of the subgrade material decreased, measured by an increasing linear shrinkage and plasticity index.

With these fundamental questions validated, the indicative mix design procedure was able to be developed. There were three variables selected for assessment of untreated basegrade material blends that would guide the user towards selection of a number of trial mix designs to be undertaken in the laboratory. The first was the particle size distribution and specifically assessment of the fines (or percent passing the 0.075mm sieve). The recommended range for a basegrade stabilisation mix design to be considered appropriate was 25-55% which was based on existing gradings of the nine pavement types and the UCS results. A complete particle size distribution curve has also been developed and recommended to characterise a basegrade pavement and assess any blend of granular and subgrade materials.

The second property that provided a high degree of conforming UCS test results was the linear shrinkage of the untreated mixtures. This was recommended at 14% or less for the UCS envelope to be obtained.

The third property was the proportion of subgrade to be mixed into the base layer. Less than 30% and 30-50% were the two categories developed. Each of these then produced various trial mix designs comprising the three primary binder types used in the research (lime/cement/flyash triple blend, slag/lime and lime pre-treated cement/flyash) and accompanying application rates. The triple blends recommended incorporated either 30% or 50% lime respectively, as these blends produced the most consistent results.

Once the user selects a mix design/s to trial, the procedure also provides guidance for when laboratory results do not satisfy the 1-2MPa strength range. These include:

- Trialling a different mix design that could be an adjustment of binder type or content;
- Plotting the results obtained and interpolating the binder content;
- Adjusting the proportion of lime within the blend, as all trial blend have a component of lime in them and this element is considered the critical element to address the plasticity and linear shrinkage properties that have an influence over the resulting strength that can be achieved.

The variation in UCS results from all tests conducted provide a high level of confidence that the desired strength range can be achieved in most circumstances using one or more of the trial mix designs used in this research, with 80% achieving between 0.8MPa and 2.6MPa. For the results that were below 1MPa, an increase in binder content may achieve the target outcome. The converse is the same for those results that exceeded 2MPa.

For the stabilised materials, Atterberg Limits were assessed. The 10^{th} to 90^{th} percentile range was 2.6%-6.4% for linear shrinkage and 2.8%-7.8% for plasticity index. These properties are considered acceptable for pavement materials in a lightly trafficked local government environment based on the literature review (AustStab, 2012; Hodgkinson, 1996; Serruto & Pardo, 2001).

One of the most encouraging trends in the results was the relatively small change in UCS with variations in the basegrade materials. This concept can be reflected in field conditions, usually under two situations. The first is when changes in material type occur within a project site (eg. from a clay to a silt). This was represented in the experimental research by assessing the test results against the three different subgrade materials (Pittsworth Alluvial v Redlands Silt v Wallum Court Clay). The

average change in UCS regardless of binder type was approximately 0.25-0.5MPa for every +/-1% change in binder application rate.
The second situation to present variations in basegrade material properties is when the proportion of subgrade changes in the field. This is relatively common where the thickness of existing pavement gravels vary along the length of a site. The average change in UCS regardless of binder type or application rate was approximately 0.5MPa for every +/- 15% subgrade inclusion.

There are a number of areas that have been identified for further research that will enhance the optimisation of the basegrade stabilisation mix design procedure. These are detailed in Section 10.

The indicative mix design procedure for basegrade stabilisation is recommended to be implemented within the local government sector as an asset management tool to aid in the maintenance of their road networks.

10 RECOMMENDATIONS FOR FURTHER RESEARCH

Throughout this research there were a number of areas that presented opportunities for further research to be undertaken that would enable refinement of the work presented in this thesis. The mix design procedure developed from this research has applications in local government in its current form, however further work in the areas identified below can introduce efficiencies into the mix design process, potentially offer a greater scope of trial mix designs and will increase the probability of achieving the desired strength target. These are summarised below, in no particular order.

10.1 Laboratory Testing

i) UCS testing curing conditions. Whilst the 28 day ambient temperature cured test is widely accepted in all Australian states, the reality of waiting this long for test results can hinder progression of a mix design program. 7 day testing under accelerated curing conditions similar to the test method used by TfNSW (T116) could be trialled for various basegrade pavement types and binders to establish a shorter time frame to obtain results. Accelerated curing would be recommended where the binders used are slow setting, defined as having a working time greater than 6hrs (Transport for NSW, 2012).

ii) National harmonisation of UCS testing to regulate the compaction process (ie. standard versus modified) and regulation of the specimen moulded moisture content to be based on a percentage of the OMC of material after the addition of the selected binder.

iii) Development of a laboratory test method to simulate the second day of mixing of another binder into a lime pre-treated material. The test method used in this research facilitated the blending of two binders at different times in line with TMR's Q135A. Application of this test method in all state road authorities would benefit future basegrade stabilisation work at a project level.

iv) The target laboratory density ratio used in this research was 100%. Samples with a lower density ratio (ie. 95%) could be trialled to assess if the expected reduction in UCS strength of 5% for each 1% drop in density (TMR, 2020c) would apply to basegrade pavement types. This would reflect situations in field construction where weak subgrades affect the ability of higher densities to be achieved.

v) As the basegrade stabilisation concept intends on having the treated pavement sitting directly on the untreated subgrade, further research on effects of capillary rise would provide useful data. Although there is limited information in upper limits of capillary rise, a 25% maximum rise up the test specimen in 24hrs has been reported as a reasonable target (Austroads, 2002).

10.2 Raw Materials

vi) With only a single granular material used in this research (Type 2.3 crushed rock), further work should be carried out with alternative granular materials. The initial focus should be to replicate several existing pavements that have signs of degradation and/or weathering. With the gravel used in this research having a CBR of 70%, identifying gravels with lower CBR values could be a useful starting point.

vii) Although the three subgrade materials used in this research enabled generation of nine pavement types, additional subgrade materials with properties differing from those used in this research could be examined. Of particular interest would be the evaluation of basegrade pavement types with expansive subgrade materials.

10.3 Stabilisation Binders

viii) Trialing different triple blends comprising slag at various proportions as a replacement to the cement component of the lime/cement/flyash binder would provide a more sustainable and environmentally friendly product if successful.

ix) Evaluations with dry powdered polymer binders could add value to the suite of options available to trial at mix design stage. These binders are well suited to materials that exhibit clayey gravels (Rodway, 2001) due to having lime blended with the polymer coated in flyash.

x) For the mix design trials undertaken in this research comprising the initial lime treatment which was ameliorated for 24 hours, followed by the addition of 70/30 cement flyash blends, multiple variations to this testing phase could be explored, viz:

- Variations in the lime content for the initial treatment to explore optimisation of that element, where a standard 3% only was used in this research. Application rates of 2% and 4% could be a valuable starting point.
- Extended amelioration times beyond 24 hours may provide beneficial outcomes that could be reflected in the field where delays occur after the initial lime treatment.
- Variations in the cement/flyash blend could be trialled, such as slag/limes, slag/cement or other cementitious blends.

10.4 Field Validation

xi) Although the plasticity index of the nine pavement types in this research were all less than 10%, it would be beneficial to assess any loss in adhesion with bituminous spray seals compared to current base layer materials that are not classified as a basegrade mixture.

xii) Evaluation of the performance of basegrade stabilisation projects over the long term will further increase the confidence of its use in the field. Correlation of performance with different road classifications and traffic loadings will consolidate the scope of application which is currently based on design traffic (DESA).

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Appendix A:

Stabilising Binder Test Reports

SLAG TEST CERTIFICATE

FINAL

Prior Related Certificates: None

Wagners Pinkenba Cement Laboratory
Address: 47 Pamela St, Pinkenba QLD 4009
Phone: (+61) 7 3621 1111
Fax: (+61) 7 3621 1100

Office Email: Pinkenba@wagner.com.au
Laboratory Email: Lab.Admin@wagner.com.au
Website: www.wagner.com.au

Certificate Number: C20-486
Product: M22
Sample Identification: WQP200504-0015
Description: GGBFS
Testing Condition As received
Sampling Location: Weighbridge 4, Silo 12 as per AS2349
Slag Source: JFE Minerals

Certificate Issued: Friday, 17 July 2020
Sample Date: Monday, 4 May 2020
Date Received: Tuesday, 5 May 2020

TEST RESULTS

Test	Fineness Index m²/kg	45µ Sieve Residue %	Moisture %	Loss on Ignition %
Result	465	97.1	0.2	0.2
Standard:	AS/NZS 2350.8	AS/NZS 2350.9	AS/NZS 2350.2	AS/NZS 2350.2
AS 3582.2 Limit	None	None	None	None

Test	MgO %	Al2O3 %	Fe_2O_3 %	MnO %	SO_3 %	Na_2O eq. %	Cl %
Result	6.0	13.3	0.4	0.1	0.5	0.4	<0.004%
Standard:	AS/NZS 2350.2	AS/NZS 2350.2	AS/NZS 2350.2	AS/NZS 2350.2	AS/NZS 2350.2	AS/NZS 2350.2	AS/NZS 2350.2
AS 3582.2 Limit	15.0	18.0	None	None	None	None	0.1

Remarks:

The above results apply only to the sample as described above.
Sample and sampling detail supplied by client.
Equivalent Sodium (NaEq) is a total value.
This documement shall only be reproduced in full unless otherwise authorised in writing from Wagners Cement P/L

NATA
WORLD RECOGNISED ACCREDITATION

Accredited for compliance with ISO/IEC 17025 - Testing

Accreditation No.17004

The results of the tests, calibraitons and/or measurements included in this document are traceable to Australian/national standards

_______________Signatory: Tanya Norris

Boral Construction Materials
Materials Technical Services
Unit 4, 3-5 Gibbon Road
Baulkham Hills NSW 2153 Australia
PO Box 400, Winston Hills NSW 2153
T: +61 (02) 9624 9900
F: +61 (02) 9624 9999
www.boral.com.au

TEST REPORT – MILLED SLAG

CLIENT: WAGNERS QUEENSLAND PTY. LTD
Address: PO Box 1394, Eagle Farm BC, QLD 4009

FILE NO: 728/20

REQUEST NO: 89344

LAB SAMPLE NO: 239658

SOURCE OF SAMPLE: Wagners

DATE RECEIVED: 14/05/2020

SAMPLE IDENTIFICATION: Slag – M22 – 2005 - 0015

IDENTIFICATION OF CEMENT USED: Boral Cement SL Berrima Ref. 2019

TEST METHOD: AS3583: Methods of test for supplementary cementitious materials for use with Portland cement

PROPERTY	TEST METHOD	RESULT	DATE TESTED
Relative density	AS3583.5	2.84	27/05/2020
Relative water requirement	AS3583.6	100%	28/05/2020
Relative strength 7 days (accelerated)	AS3583.6	101%	04/06/2020
Relative strength 28 days (standard)	AS3583.6	86%	25/06/2020

Note:

- Sample supplied by the client and tested as received.

Boris Humpola, Mat. File, File

Approved Signatory Julius C. Alvaro Julius Alvaro
Date 26/06/2020 Serial No. CEM89344.JA.1

ACCREDITED FOR TECHNICAL COMPETENCE

NATA Accredited Laboratory
Number: 547

Report Template – Rev. (2) April 2017 – Authorised by M.A.

BORAL®

Boral Construction Materials
Materials Technical Services

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Baulkham Hills NSW 2153 Australia
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www.boral.com.au

TEST REPORT

CLIENT: WAGNERS QUEENSLAND PTY LTD
B.O.Box 1394, Eagle Farm BC, QLD 4009.

FILE No.:728/20

PROJECT: Testing of Slag samples.

REQUEST No.: 89344

TEST PROCEDURE:
AS 3583.12 – 1991 – Determination of Available Alkali

Laboratory Sample No.:	239658
Date Sampled:	Unknown
Date Received:	14/05/20
Sample Description:	Slag – M22 – 2005-0015
Field No.:	1

TEST RESULTS:

Sodium as Na_2O (%)	0.03
Potassium as K_2O (%)	0.07
Available Alkali (%)	0.1

Available Alkali (%) = Na_2O (%) + (0.658 x K_2O %)

Note:

- Samples submitted by the Client.
- Test results in this Test Report relate only to the sample tested
- This report shall not be reproduced except in full without the approval of the Boral MTS Laboratory

B.Humpola, Mat. File, File.

NATA
ACCREDITED FOR TECHNICAL COMPETENCE

Approved Signatory [signature] Nanthini Selvadurai

Date 26-06-20 Serial No. CHEM89344.NS.1

Accredited for compliance with ISO/IEC 17025

NATA Accredited Laboratory
Number: 9968

Report Template – Rev. (2) April 2017 – Authorised by M.A.

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www.boral.com.au

TEST REPORT

FILE No.: 728/20

CLIENT: WAGNERS QUEENSLAND PTY LTD
P.O.Box 1394, Eagle Farm BC, QLD 4009

PROJECT: Testing of Slag Samples

REQUEST No.: 89344

TEST PROCEDURE:
AS 3583.14 - 1991 – Determination of Insoluble Residue

Laboratory Sample No.:	239658
Date Sampled:	Unknown
Date Tested :	18/06/20
Sample Description:	Slag - M22 -2005 - 0015
Field No.:	1

TEST RESULTS:

Insoluble Residue (%)	0.3

Note:

- Sample submitted by the Client.
- Test results in this Test Report relate only to the samples tested
- This report shall not be reproduced except in full without the approval of the Boral MTS Laboratory

B.Humpola, Mat. File, File.

Approved Signatory [signature] Nanthini Selvadurai

Date 26-06-20 Serial No. CHEM89344NS.2

ACCREDITED FOR TECHNICAL COMPETENCE

Accredited for compliance with ISO/IEC 17025

NATA Accredited Laboratory
Number: 9968

BR20100802 - Finalized
CLIENT : "WAGCEM - Wagners Queensland Pty Ltd"
# of SAMPLES : 2
DATE RECEIVED : 2020-05-13 DATE FINALIZED : 2020-06-09
PROJECT : "Slag External testing"
CERTIFICATE COMMENTS : ""
PO NUMBER : "4500270839"

	WEI-21b	S-IR08	S-ICP16
SAMPLE	Pulp Wt	S	SO4asS
DESCRIPTION	g	%	%
2005_0015 M22	203	0.99	0.45

S-CAL07
Sulphide S
%
0.54

Graymont
ABN 24 004 406688
APAC Central Laboratory
49-55 Woodlands Drive, BRAESIDE, VICTORIA 3195
Phone: +61 3 9586 5400
Email: otsc@graymont.com

Laboratory Report

FINAL REPORT **Report No:** **72532**

Ref No: 4TA-202005-0018

Sample Supplier: Tony Gillieatt
GRAYMONT
276 Tamaree Road
Gympie, QLD, 4570

Sample Identification: Hydrated Lime
625-HYD-0420

Testing Frequency
MONTHLY_NATA

METHOD LIST

Method	Test	References
LMM 8.5	Chemical Analysis by XRF	
LMM2.3(a)	Loss on Ignition	
LMM4.19	Available Lime	AS4489.6.1 Lime Index - Available Lime
LMM4.20	Voids	AS1141.17 Voids in Dry Compacted Filler
LMM4.21	Apparent Density	AS1141.7 Apparent Particle Density of Filler
LMM 2.2c	Moisture	AS4489.8.1 Free Moisture - Convection Oven
LMM 2.5(b)	Wet Screen Analysis	
LMM 4.27	ALS Trace Analysis	ALS Methods WK026SF, WK040LL, WG020A

Important Notes

1. This is a final report and it supersedes any previous interim reports pertaining to this work that you may have received
2. The results in this report pertain to samples as submitted to the laboratory
This report shall not reproduced except in full and with the approval of this Laboratory.

To view the Measurement Uncertainty (MU) values of the tests displayed, please communicate with this facility using one of the above contact details.

These tests were completed on the following Dates: *03-May-20 , 19-May-20 , 18-May-20 , 26-May-20*

Date Issued	Checked By	
26-May-2020	Jibo Wang	Chemist

NATA Accreditation No. 1614
Accredited for compliance with ISO/IEC 17025 - Testing.

The results of the tests/calibrations and/or measurements included in this document are traceable to

Chemistry

			325895 **625-HYD-0420**
Chemical Analysis by XRF	SiO2	%	1.3
	Fe2O3	%	0.12
	TiO2	%	<0.01
	Al2O3	%	0.21
	CaO	%	72.6
	MgO	%	0.62
	Na2O	%	0.03
	K2O	%	0.07
Loss on Ignition	LOI	%	24.8

Physical

			325895 **625-HYD-0420**
Available Lime	Available Lime as	%Ca(OH)2	93.4
Voids	Voids	%	51.0
Apparent Density	Density of Filler	t/m3	2.230
Moisture	Moisture	%	0.7
Wet Screen Analysis	600µm %Retained	%	0.0
	300µm %Retained	%	0.1
	150µm %Retained	%	0.6
	75µm %Retained	%	3.8
	600µm %Passing	%	100.0
	300µm %Passing	%	99.9
	150µm %Passing	%	99.4
	75µm %Passing	%	96.2

External Analysis

			325895 **625-HYD-0420**
ALS Trace Analysis	Laboratory Name	-	ALS Group
	Location	-	Scoresby, Vic
	Accreditation No	-	992
	Report No	-	826675
	Sample No	-	6563854
	Fluoride as F	mg/kg	50
	Total Cyanide as	mg/kg	<5
	Aluminium	mg/kg	<100
	Antimony	mg/kg	<10
	Arsenic	mg/kg	<10
	Barium	mg/kg	<10
	Beryllium	mg/kg	<10

			325895 **625-HYD-0420**
ALS Trace Analysis	Boron	mg/kg	<200
	Cadmium	mg/kg	<2
	Chromium	mg/kg	<10
	Cobalt	mg/kg	<10
	Copper	mg/kg	<10
	Iron	mg/kg	<200
	Lead	mg/kg	<10
	Manganese	mg/kg	<10
	Mercury	mg/kg	<1
	Molybdenum	mg/kg	<10
	Nickel	mg/kg	<10
	Selenium	mg/kg	<10
	Silver	mg/kg	<10
	Strontium	mg/kg	150
	Thallium	mg/kg	<10
	Tin	mg/kg	<10
	Titantium	mg/kg	<10
	Vanadium	mg/kg	<10
	Zinc	mg/kg	<10

STANDARD FLY ASH CERTIFICATE

MILLMERRAN FLYASH
SUSTAINABLE STRENGTH

FINAL
Prior Reports: None

Certificate Number: CERT200916
Issued: 06 May 2020

Independent Flyash Brokers Pty Ltd
Head Office
431 Moffatt Reserve
Millmerran QLD 4357
Tel : (07) 4695 6033
Fax: (07) 4695 6133
www.mflyash.com.au

Product being certified:	Independent Flyash Broker Monthly Grab Fly Ash
Product sample date:	14-Apr-2020
Sample Identification:	Sample Code: 20040583
Source Power Station:	Millmerran Power Station
Sample Condition:	Tested as Received. Testing Commenced on 17-Apr-2020
Certifying Laboratory:	Cement Australia - Darra Laboratory, 18 Station Avenue, Darra Queensland 4076 Australia.

Test Results

Test	Moisture %	Fineness @ 45 micron % Passed	Loss on Ignition %	Sulfuric Anhydride %	Available Alkali %	Chloride Ion %	Chemical Composition %
Result	< 0.1	86	0.3	0.1	Not Tested	0.001	94.8
Test Method	AS3583.2	AS3583.1	AS3583.3	AS2350.2	AS3583.12	AS3583.13	AS2350.2
AS 3582.1	0.5 % Maximum	75% Minimum	4.0 % Maximum	3.0 % Maximum	-	0.1 % Maximum	70% Minimum

Test	Relative Density	Relative Water Requirement %	Strength Index 7 Day Acc. %
Result	1.82	95	93
Test Method	AS3583.5	AS3583.6	AS3583.6
AS 3582.1	-	-	75% Minimum

Reference Cement Details

Identification:: 20040751
Source: Goliath GP
Product Type: Type GP
Sample Date: 21-Apr-20

Additional Testing - Oxides

Test	CaO by XRF %	SiO_2 by XRF %	Al_2O_3 by XRF %	Fe_2O_3 by XRF %	SO_3 by XRF %	MgO by XRF %	Na_2O by XRF %
Result	1.4	58.0	34.3	2.5	0.1	0.8	0.37
Test Method	AS2350.2	AS2350.2	AS2350.2	AS2350.2	AS2350.2	AS2350.2	AS2350.2

Test	K_2O by XRF %	SrO by XRF %	TiO2 by XRF %	P_2O_5 by XRF %	Mn_2O_3 by XRF %	Total Alkali (NaEQ) %
Result	0.69	<0.1	1.8	0.2	< 0.1	0.82
Test Method	AS2350.2	AS2350.2	AS2350.2	AS2350.2	AS2350.2	AS2350.2

This sample grade conforms to the following requirements of AS 3582.1:2016

Special	Grade 1	Grade 2
	X	

Approved Signatory

A Prem
Signatory - Cement Australia
Chemical Testing
Construction Materials Testing

Accredited for compliance with ISO/IEC 17025 - Testing. The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards.

Cement Australia - Darra Laboratory
NATA Accredited Laboratory Numbers
187 188

NATA
ACCREDITED FOR TECHNICAL COMPETENCE

Notes:

2 0 0 4 0 5 8 3

C E R T 2 0 0 9 1 6

CEMENT TEST CERTIFICATE
FINAL
Prior Related Certificates: None

Wagners Pinkenba Cement Laboratory
Address: 47 Pamela St, Pinkenba QLD 4009
Phone: (+61) 7 3621 1111
Fax: (+61) 7 3621 1100

Office Email: Pinkenba@wagner.com.au
Laboratory Email: Lab.Admin@wagner.com.au
Website: www.wagner.com.au

Certificate Number:	C20-393	**Certificate Issued:**	16 July 2020
Product to be certified:	GP Cement	**Sample Date:**	15 June 2020
Sample Identification:	WQP200615-0197	**Date Received:**	17 June 2020
Description:	Routine sample taken from product stream to despatch tanker		
Testing Condition	As received		

TEST RESULTS

Test	Fineness Index m²/kg	45μ Sieve Residue %	Normal Consistency %	Initial Setting min	Final Setting min	Soundness mm	Loss on Ignition %
Result	375	3.2	28.0	135	210	1	1.5
Standard:	AS/NZS 2350.8	AS/NZS 2350.9	AS/NZS 2350.3	AS/NZS 2350.4	AS/NZS 2350.4	AS/NZS 2350.5	AS/NZS 2350.2
AS 3972 Limit	None	None	None	45 minutes Minimum	360 Minutes Maximum	5mm Maximum	None

Mortar Compressive Strength

Test	3 days MPa	7 days MPa	28days MPa
Result	35.5	46.5	67.4
Standard:	AS/NZS 2350.11	AS/NZS 2350.11	AS/NZS 2350.11
AS 3972 Limit	None	35MPa min.	45MPa min.

Test	CaO %	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	SO_3 %	Na_2O eq. %	Cl %
Result	64.2	21.1	5.4	3.1	2.9	0.5	0.011
Standard:	AS/NZS 2350.2	AS/NZS 2350.2	AS/NZS 2350.2	AS/NZS 2350.2	AS/NZS 2350.2	AS/NZS 2350.2	AS/NZS 2350.2 in-house XRF
AS 3972 Limit	None	None	None	None	3.5% Maximum	None	0.1% Maximum

Remarks:
The above results apply only to the sample as described above.
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The results of the tests, calibraitons and/or measurements included in this document are traceable to Australian/national standards

Signatory: Tanya Norris

Appendix B:

Laboratory Test Reports, Testing Phase 1 - Raw Materials

Material Test Report

Report Number:	**BTK 20018-1**
Issue Number:	3 - *This version supersedes all previous issues*
Reissue Reason:	*Change Location wording*
Date Issued:	27/08/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Hybrid Pavement Stabilisation Research
Work Request:	726
Sample Number:	20-726A
Date Sampled:	15/07/2020
Dates Tested:	21/07/2020 - 21/07/2020
Sampling Method:	Sampled by Client *The results apply to the sample as received*
Sample Location:	**Raw Material 2 - Pittsworth Alluvial, Depth: As Delivered**
Lot No:	**Raw Material 2**
Sub Lot No:	**Pittsworth Alluvial**
Material:	Raw Materials - Quality and Classification Tests

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Approved Signatory: James Dick
Manager

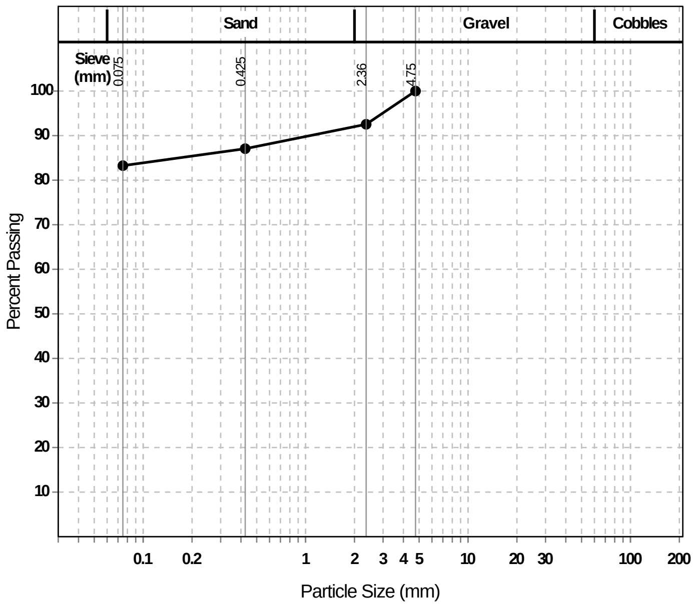
NATA Accredited Laboratory Number: 2851

Atterberg Limit (Q104A & Q105 & AS 1289.2.1.1)		Min	Max
Sample History	Oven Dried		
Preparation Method	Dry Sieve		
Liquid Limit (%)	82.4		
Plastic Limit (%)	33.0		
Plasticity Index (%)	**49.4**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	21.4		

Particle Size Distribution (Q103A & AS 1289.2.1.1)			
Sieve	Passed %	Passing Limits	
4.75 mm	**100**		
2.36 mm	**93**		
0.425 mm	**87**		
0.075 mm	**83**		

Particle Size Distribution



Material Test Report

Report Number:	**BTK 20018-1**
Issue Number:	3 - *This version supersedes all previous issues*
Reissue Reason:	*Change Location wording*
Date Issued:	27/08/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Hybrid Pavement Stabilisation Research
Work Request:	726
Sample Number:	20-726B
Date Sampled:	15/07/2020
Dates Tested:	21/07/2020 - 21/07/2020
Sample Location:	**Raw Material 1 - Boral Quarry Burleigh Heads, Depth: As Delivered**
Lot No:	**Raw Material 1**
Sub Lot No:	**Boral 2.3 Gravel**
Material:	Raw Materials - Quality and Classification Tests

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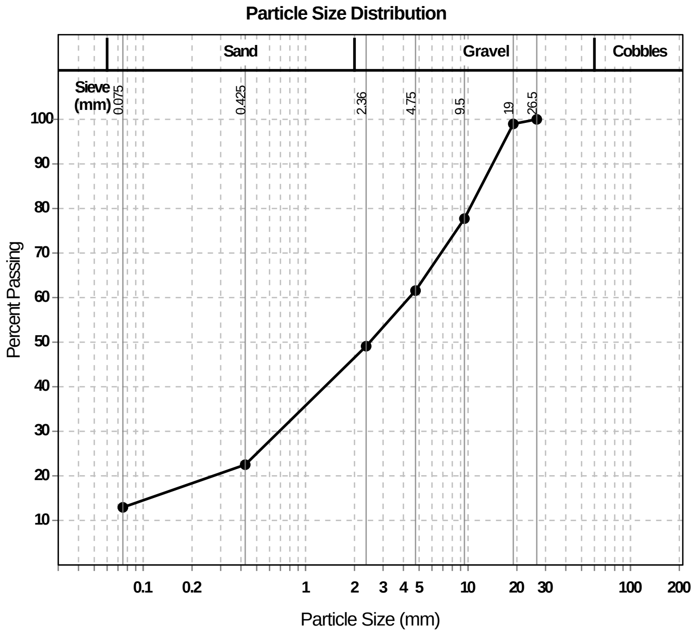
Approved Signatory: James Dick
Manager

NATA Accredited Laboratory Number: 2851

Atterberg Limit (Q104A & Q105 & AS 1289.2.1.1)		Min	Max
Sample History	Oven Dried		
Preparation Method	Dry Sieve		
Liquid Limit (%)	19.6		
Plastic Limit (%)	17.6		
Plasticity Index (%)	**2.0**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Air Dried		
Linear Shrinkage (%)	1.4		

Particle Size Distribution (Q103A & AS 1289.2.1.1)			
Sieve	Passed %	Passing Limits	
26.5 mm	**100**		
19 mm	**99**		
9.5 mm	**78**		
4.75 mm	**62**		
2.36 mm	**49**		
0.425 mm	**22**		
0.075 mm	**13**		



Material Test Report

Report Number: **BTK 20018-1**
Issue Number: 3 - *This version supersedes all previous issues*
Reissue Reason: *Change Location wording*
Date Issued: 27/08/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Hybrid Pavement Stabilisation Research
Work Request: 726
Sample Number: 20-726C
Date Sampled: 15/07/2020
Dates Tested: 21/07/2020 - 21/07/2020
Sampling Method: Q060 8.3 - Single layer formed stockpile – hand tools
Site Selection: Selected by Client
Sample Location: **Redlands SILT - Raw material 3**
Lot No: **Raw Material 3 - Redlands SILT**
Sub Lot No: **Birkdale Site**
Material: Raw Materials - Quality and Classification Tests

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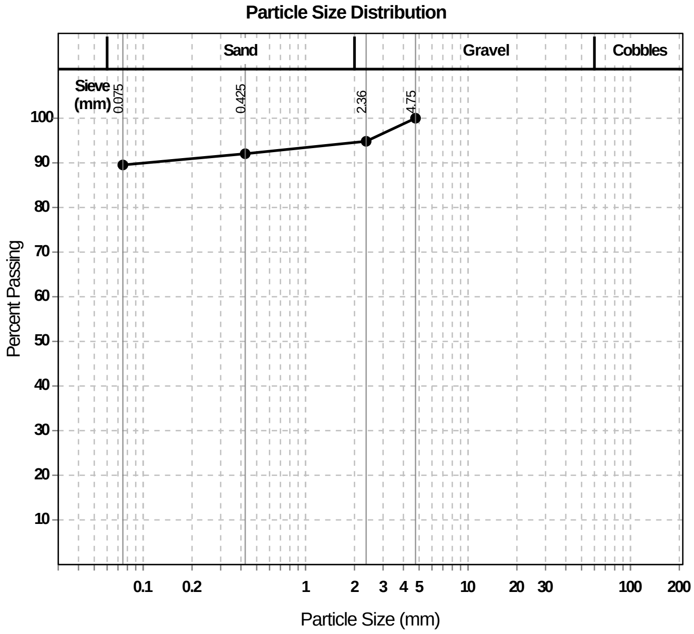
Manager
NATA Accredited Laboratory Number: 2851

Atterberg Limit (Q104A & Q105 & AS 1289.2.1.1)		Min	Max
Sample History	Oven Dried		
Preparation Method	Dry Sieve		
Liquid Limit (%)	65.4		
Plastic Limit (%)	37.0		
Plasticity Index (%)	**28.4**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried / Air Dried		
Linear Shrinkage (%)	16.0		

Particle Size Distribution (Q103A & AS 1289.2.1.1)			
Sieve	Passed %	Passing Limits	
4.75 mm	**100**		
2.36 mm	**95**		
0.425 mm	**92**		
0.075 mm	**90**		



Material Test Report

Report Number: **BTK 20018-2**
Issue Number: 3 - *This version supersedes all previous issues*
Reissue Reason: *Change to location description*
Date Issued: 27/08/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Hybrid Pavement Stabilisation Research
Work Request: 734
Sample Number: 20-734A
Date Sampled: 23/07/2020
Dates Tested: 24/07/2020 - 28/07/2020
Sampling Method: Q060 8.4 [2018] - Single layer formed stockpile - hand tools
Site Selection: Selected by Border-Tek Technician
Sample Location: **Raw Material 4 - Wallum Court Clothiers Creek**
Material: Sandy silty CLAY pale yellow brown

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Manager

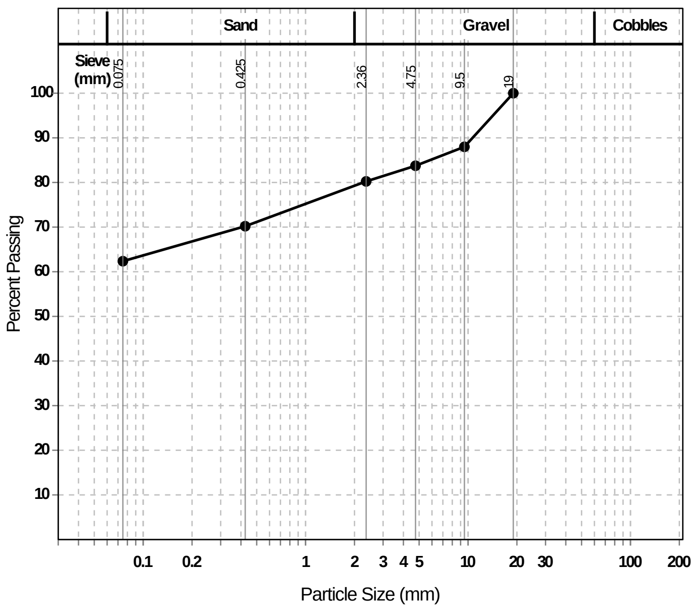
NATA Accredited Laboratory Number: 2851

Atterberg Limit (Q104A & Q105 & AS 1289.2.1.1)		Min	Max
Sample History	Oven Dried		
Preparation Method	Dry Sieve		
Liquid Limit (%)	38.8		
Plastic Limit (%)	24.6		
Plasticity Index (%)	**14.2**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	3.4		

Particle Size Distribution (Q103A & AS 1289.2.1.1)			
Sieve	Passed %	Passing Limits	
19 mm	**100**		
9.5 mm	**88**		
4.75 mm	**84**		
2.36 mm	**80**		
0.425 mm	**70**		
0.075 mm	**62**		

Particle Size Distribution



Material Test Report

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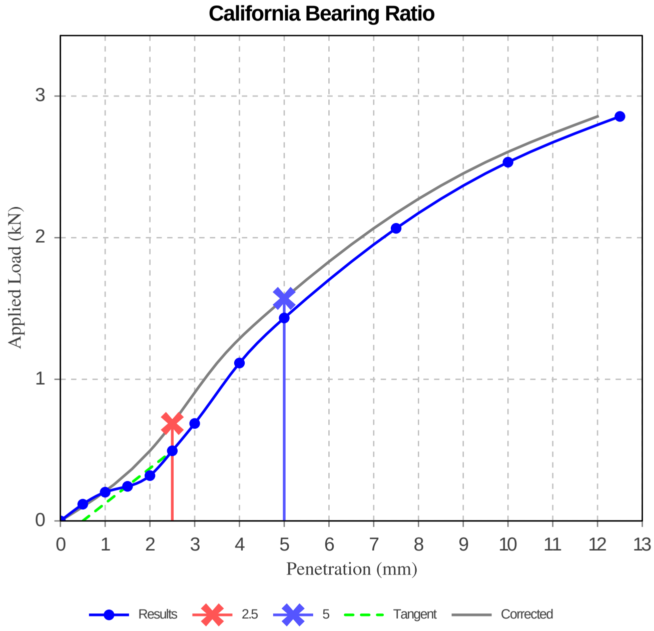
Approved Signatory: James Dick
Manager
NATA Accredited Laboratory Number: 2851

Report Number:	**BTK 20018-2**
Issue Number:	3 - *This version supersedes all previous issues*
Reissue Reason:	*Change to location description*
Date Issued:	27/08/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Hybrid Pavement Stabilisation Research
Work Request:	734
Sample Number:	20-734A
Date Sampled:	23/07/2020
Dates Tested:	24/07/2020 - 30/07/2020
Sampling Method:	Q060 8.4 [2018] - Single layer formed stockpile - hand tools
Site Selection:	Selected by Border-Tek Technician
Sample Location:	**Raw Material 4 - Wallum Court Clothiers Creek**
Material:	Sandy silty CLAY pale yellow brown

California Bearing Ratio (Q113C & AS 1289.2.1.1)		Min	Max
CBR % (at 2.5 mm)	5		
CBR % (at 5 mm)	8		
CBR %	**8**		
Method of Compactive Effort	Standard		
Method used to Determine MDD	Q142A & AS 1289.2.1.1		
Maximum Dry Density (t/m^3)	1.68		
Optimum Moisture Content (%)	21.0		
Target Dry Density (t/m^3)	1.68		
Achieved Dry Density (t/m^3)	1.68		
Target Laboratory Density Ratio (%)	100		
Laboratory Density Ratio (%)	100.0		
Target Moisture Content (%)	20.9		
Achieved Moisture Content (%)	20.9		
Target Laboratory Moisture Ratio (%)	100		
Laboratory Moisture Ratio (%)	100.0		
Moisture Content at Placement (%)	20.9		
Moisture Content Top 30mm (%)	25.1		
Moisture Content Rest of Sample (%)	24.2		
Mass Surcharge (kg)	4.5		
Soaking Period (days)	4		
Test Condition	Soaked		
Swell (%)	1.9		
Oversize Material (mm)	19		
Oversize Material Included	Excluded		
Oversize Material (%)	0		



Material Test Report

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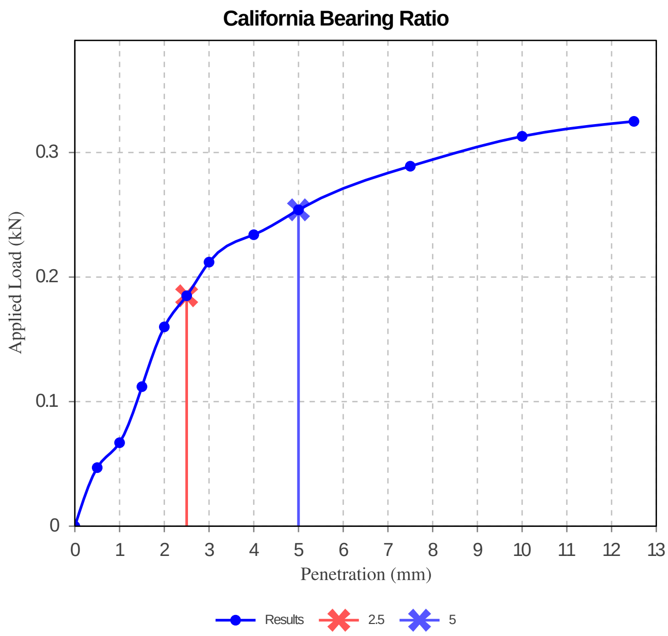
Manager
NATA Accredited Laboratory Number: 2851

Report Number: **BTK 20018-3**
Issue Number: 2 - *This version supersedes all previous issues*
Reissue Reason: *Change Location Wording*
Date Issued: 27/08/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Hybrid Pavement Stabilisation Research
Work Request: 732
Sample Number: 20-732A
Date Sampled: 23/07/2020
Dates Tested: 24/07/2020 - 30/07/2020
Sampling Method: Sampled by Client
The results apply to the sample as received
Sample Location: **Pittsworth Alluvial - Raw Material 2, Depth: Sample Supplied**
Lot No: **Raw Material 2 - CBR Testing**
Sub Lot No: **Pittsworth Alluvial**

California Bearing Ratio (Q113C & AS 1289.2.1.1)		Min	Max
CBR % (at 2.5 mm)	1.5		
CBR % (at 5 mm)	1.5		
CBR %	**1.5**		
Method of Compactive Effort	Standard		
Method used to Determine MDD	Q142A & AS 1289.2.1.1		
Maximum Dry Density (t/m^3)	1.34		
Optimum Moisture Content (%)	29.5		
Target Dry Density (t/m^3)	1.34		
Achieved Dry Density (t/m^3)	1.34		
Target Laboratory Density Ratio (%)	100		
Laboratory Density Ratio (%)	100.5		
Target Moisture Content (%)	29.6		
Achieved Moisture Content (%)	29.5		
Target Laboratory Moisture Ratio (%)	100		
Laboratory Moisture Ratio (%)	99.5		
Moisture Content at Placement (%)	29.5		
Moisture Content Top 30mm (%)	54.0		
Moisture Content Rest of Sample (%)	40.9		
Mass Surcharge (kg)	4.5		
Soaking Period (days)	4		
Test Condition	Soaked		
Swell (%)	0.8		
Oversize Material (mm)	19		
Oversize Material Included	Excluded		
Oversize Material (%)	0		



Material Test Report

Report Number:	**BTK 20018-4**
Issue Number:	1
Date Issued:	25/08/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Hybrid Pavement Stabilisation Research
Work Request:	733
Sample Number:	20-733A
Date Sampled:	23/07/2020
Dates Tested:	24/07/2020 - 03/08/2020
Sampling Method:	Q060 8.4 [2018] - Single layer formed stockpile - hand tools
Sample Location:	**Raw Materials - Redlands SILT - CBR Testing**
Lot No:	**Raw Materials - Redlands Silt - Raw Material 3**
Material:	Redlands SILT

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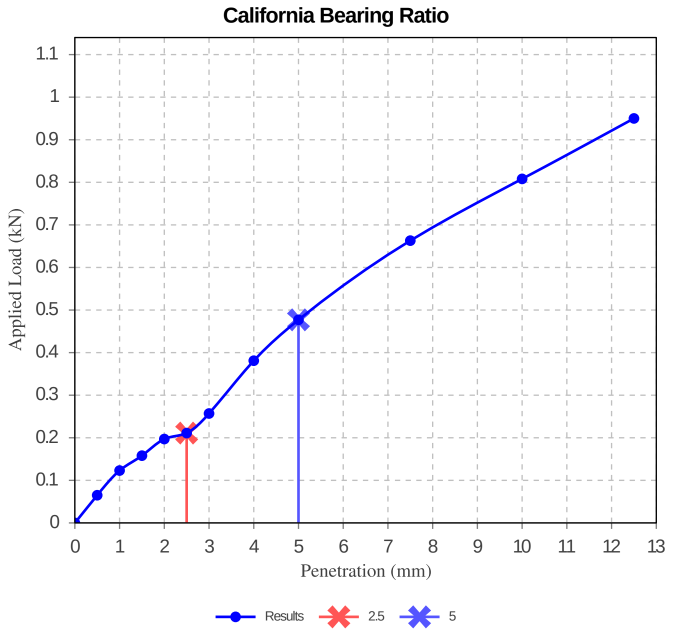
Approved Signatory: James Dick
Manager

NATA Accredited Laboratory Number: 2851

California Bearing Ratio (Q113C & AS 1289.2.1.1)		Min	Max
CBR % (at 2.5 mm)	1.5		
CBR % (at 5 mm)	2.5		
CBR %	**2.5**		
Method of Compactive Effort	Standard		
Method used to Determine MDD	Q142A & AS 1289.2.1.1		
Maximum Dry Density (t/m^3)	1.35		
Optimum Moisture Content (%)	38.0		
Target Dry Density (t/m^3)	1.35		
Achieved Dry Density (t/m^3)	1.34		
Target Laboratory Density Ratio (%)	100		
Laboratory Density Ratio (%)	99.5		
Target Moisture Content (%)	38.0		
Achieved Moisture Content (%)	37.9		
Target Laboratory Moisture Ratio (%)	100		
Laboratory Moisture Ratio (%)	99.5		
Moisture Content at Placement (%)	37.9		
Moisture Content Top 30mm (%)	43.9		
Moisture Content Rest of Sample (%)	42.7		
Mass Surcharge (kg)	4.5		
Soaking Period (days)	4		
Test Condition	Soaked		
Swell (%)	0.3		
Oversize Material (mm)	19		
Oversize Material Included	Excluded		
Oversize Material (%)	0		



Material Test Report

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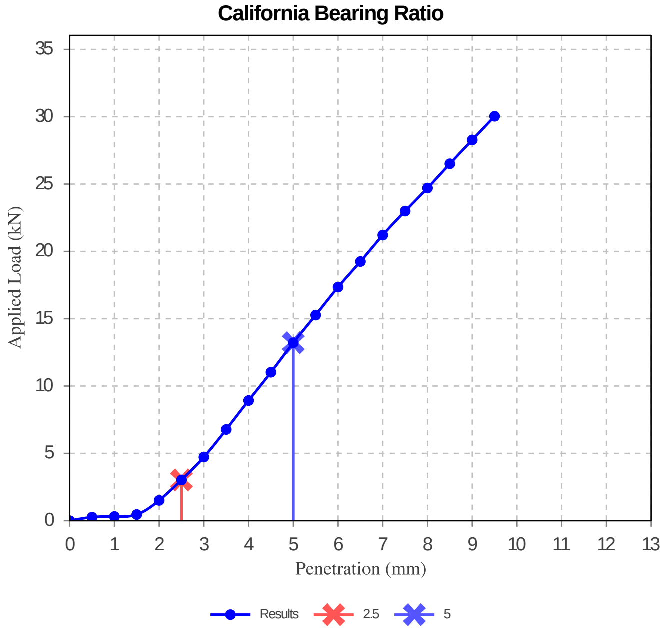
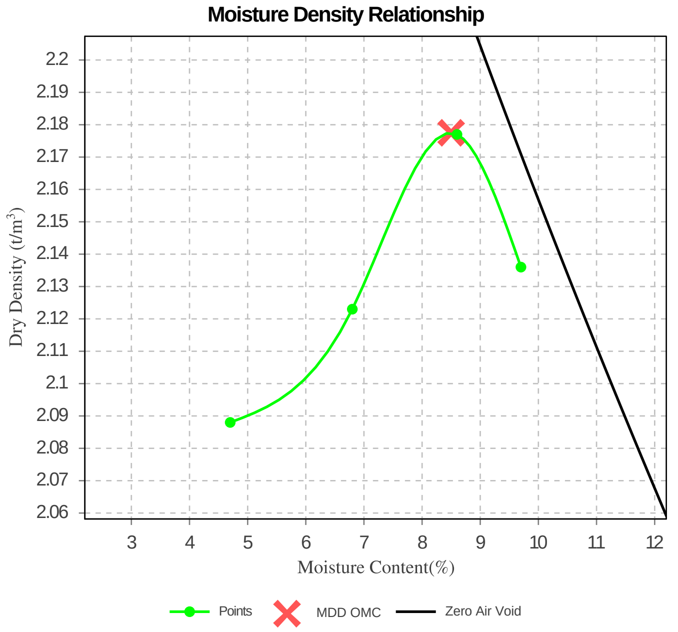
Approved Signatory: Daniel French
Senior Technical Officer
NATA Accredited Laboratory Number: 2851

Report Number: **BTK 20018-12**
Issue Number: 1
Date Issued: 21/09/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 794
Sample Number: 20-794A
Date Sampled: 20/09/2020
Dates Tested: 09/09/2020 - 14/09/2020
Sampling Method: Sampled by Client
The results apply to the sample as received
Sample Location: **Raw Materials - Boral GRAVEL (Type 2.3) - CBR Testing**
Lot No: **Raw Materials - Boral Gravel - Raw Material 1**
Material: Boral Type 2.3

California Bearing Ratio (Q113C & AS 1289.2.1.1)		Min	Max
CBR % (at 2.5 mm)	25		
CBR % (at 5 mm)	70		
CBR %	**70**		
Method of Compactive Effort	Standard		
Method used to Determine MDD	Q142A & AS 1289.2.1.1		
Method used to Determine Plasticity	Visual/Tactile		
Maximum Dry Density (t/m^3)	2.18		
Optimum Moisture Content (%)	8.5		
Target Dry Density (t/m^3)	2.18		
Achieved Dry Density (t/m^3)	2.17		
Target Laboratory Density Ratio (%)	100		
Laboratory Density Ratio (%)	99.5		
Target Moisture Content (%)	8.5		
Achieved Moisture Content (%)	8.6		
Target Laboratory Moisture Ratio (%)	100		
Laboratory Moisture Ratio (%)	101.0		
Moisture Content at Placement (%)	8.6		
Moisture Content Top 30mm (%)	8.2		
Moisture Content Rest of Sample (%)	9.1		
Mass Surcharge (kg)	4.5		
Soaking Period (days)	4		
Test Condition	Soaked		
Curing Hours	76.9		
Swell (%)	0.0		
Oversize Material (mm)	19		
Oversize Material Included	Excluded		
Oversize Material (%)	0		

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	2.18
Optimum Moisture Content (%)	8.5
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	2





Material Test Report

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Approved Signatory: Daniel French
Senior Technical Officer
NATA Accredited Laboratory Number: 2851

Report Number: **BTK 20018-12**
Issue Number: 1
Date Issued: 21/09/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 794
Sample Number: 20-794A
Date Sampled: 20/09/2020
Dates Tested: 09/09/2020 - 14/09/2020
Sampling Method: Sampled by Client
The results apply to the sample as received
Sample Location: **Raw Materials - Boral GRAVEL (Type 2.3) - CBR Testing**
Lot No: **Raw Materials - Boral Gravel - Raw Material 1**
Material: Boral Type 2.3

Moisture Content (AS 1289.2.1.1)	
Moisture Content (%)	4.7

Appendix C:

Laboratory Test Reports, Testing Phase 2 - Blended Raw Materials

Material Test Report

Report Number: **BTK 20018-5**
Issue Number: 3 - *This version supersedes all previous issues*
Reissue Reason: *Change 744H to 65/35*
Date Issued: 26/08/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Hybrid Pavement Stabilisation Research
Work Request: 744
Sample Number: 20-744A
Date Sampled: 23/07/2020
Dates Tested: 31/07/2020 - 31/07/2020
Sample Location: **PT 1 - 1 and 2 - 80/20**
Lot No: **Pavement Type 1**
Sub Lot No: **1 and 2 80/20**

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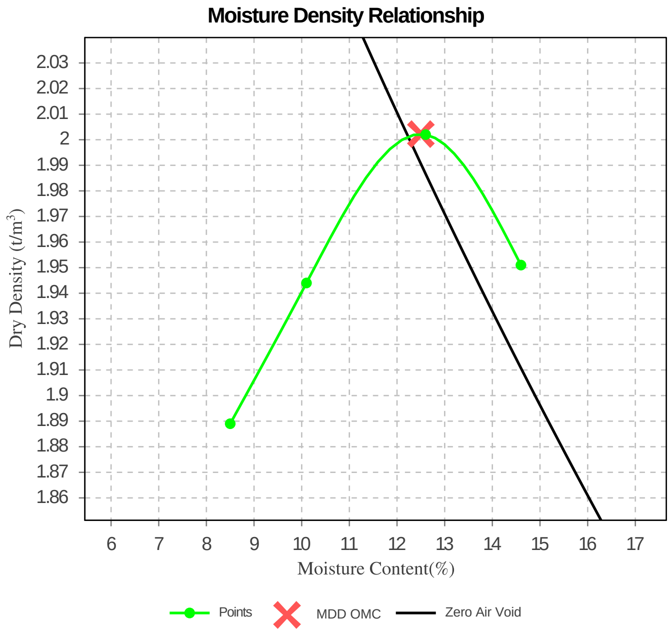
Approved Signatory: James Dick
Manager
NATA Accredited Laboratory Number: 2851

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	2.00
Optimum Moisture Content (%)	12.5
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Vis/Tac
Curing Hours	24



Material Test Report

Report Number:	**BTK 20018-5**
Issue Number:	3 - *This version supersedes all previous issues*
Reissue Reason:	*Change 744H to 65/35*
Date Issued:	26/08/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Hybrid Pavement Stabilisation Research
Work Request:	744
Sample Number:	20-744B
Date Sampled:	23/07/2020
Dates Tested:	31/07/2020 - 31/07/2020
Sample Location:	**PT2 - 1 and 2- 65/35**
Lot No:	**Pavement Type 2**
Sub Lot No:	**1 and 2 65/35**

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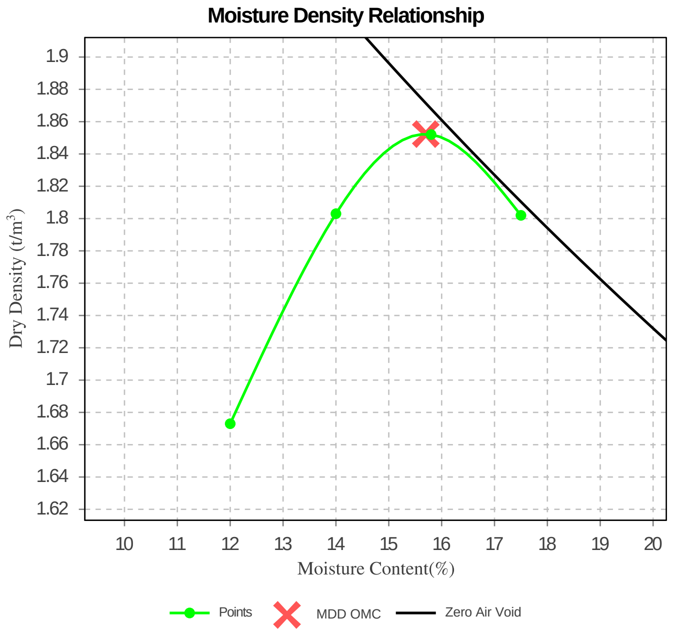
Approved Signatory: James Dick
Manager

NATA Accredited Laboratory Number: 2851

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	1.85
Optimum Moisture Content (%)	15.5
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Vis/Tac
Curing Hours	24



Material Test Report

Report Number: **BTK 20018-5**
Issue Number: 3 - *This version supersedes all previous issues*
Reissue Reason: *Change 744H to 65/35*
Date Issued: 26/08/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Hybrid Pavement Stabilisation Research
Work Request: 744
Sample Number: 20-744B
Date Sampled: 23/07/2020
Dates Tested: 31/07/2020 - 08/08/2020
Sample Location: **PT2 - 1 and 2- 65/35**
Lot No: **Pavement Type 2**
Sub Lot No: **1 and 2 65/35**

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Approved Signatory: James Dick
Manager

NATA Accredited Laboratory Number: 2851

Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	69.6		
Plastic Limit (%)	31.0		
Plasticity Index (%)	**38.6**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	13.2		

Material Test Report

Report Number: **BTK 20018-5**
Issue Number: 3 - *This version supersedes all previous issues*
Reissue Reason: *Change 744H to 65/35*
Date Issued: 26/08/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Hybrid Pavement Stabilisation Research
Work Request: 744
Sample Number: 20-744C
Date Sampled: 23/07/2020
Dates Tested: 31/07/2020 - 31/07/2020
Sample Location: **PT3 - 1 and 2 - 50/50**
Lot No: **Pavement Type 3**
Sub Lot No: **1 and 2 50/50**

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Manager

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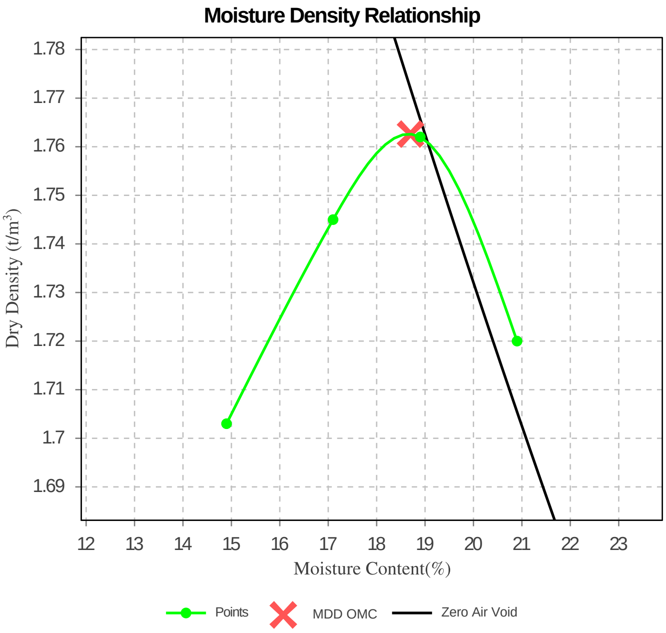
Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	1.76
Optimum Moisture Content (%)	18.5
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	24



Material Test Report

Report Number: **BTK 20018-5**
Issue Number: 3 - *This version supersedes all previous issues*
Reissue Reason: *Change 744H to 65/35*
Date Issued: 26/08/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Hybrid Pavement Stabilisation Research
Work Request: 744
Sample Number: 20-744D
Date Sampled: 23/07/2020
Dates Tested: 31/07/2020 - 31/07/2020
Sampling Method: AS 1289.1.2.1 6.2 - Sampling from stockpiles
Sample Location: **PT4 - 1 and 3 - 80/20**
Lot No: **Pavement Type 4**
Sub Lot No: **1 and 3 80/20**

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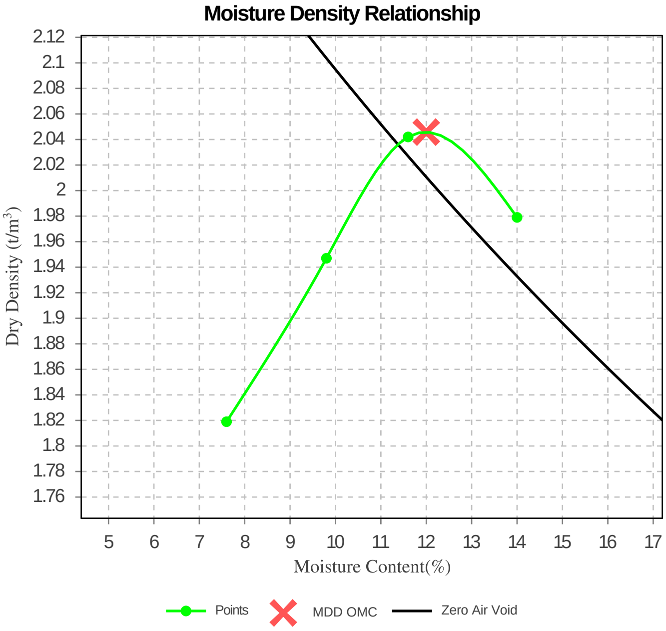
Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	2.05
Optimum Moisture Content (%)	12.0
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Vis/Tac
Curing Hours	24



Material Test Report

Report Number:	**BTK 20018-5**
Issue Number:	3 - *This version supersedes all previous issues*
Reissue Reason:	*Change 744H to 65/35*
Date Issued:	26/08/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Hybrid Pavement Stabilisation Research
Work Request:	744
Sample Number:	20-744E
Date Sampled:	23/07/2020
Dates Tested:	30/07/2020 - 30/07/2020
Sample Location:	**PT 5 - 1 and 3 - 65/35**
Lot No:	**Pavement Type 5**
Sub Lot No:	**1 and 3 65/35**

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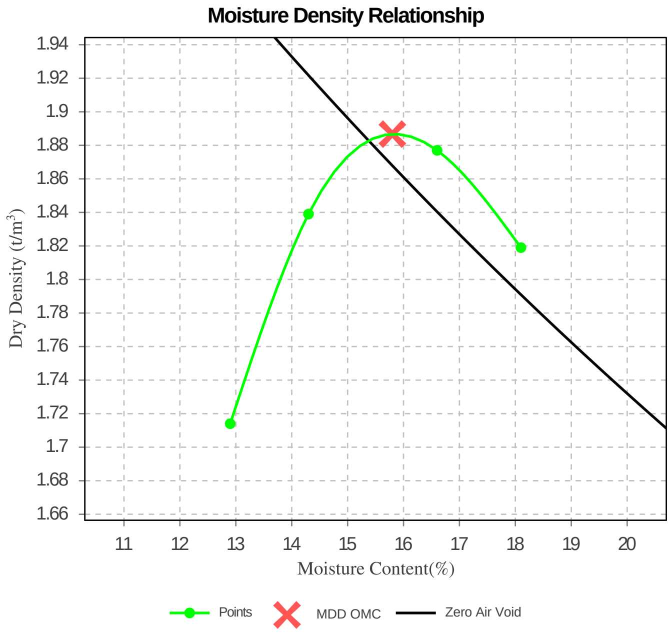
Manager

NATA Accredited Laboratory Number: 2851

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	1.89
Optimum Moisture Content (%)	16.0
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Vis/Tac
Curing Hours	24



Material Test Report

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Manager
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Report Number: **BTK 20018-5**
Issue Number: 3 - *This version supersedes all previous issues*
Reissue Reason: *Change 744H to 65/35*
Date Issued: 26/08/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Hybrid Pavement Stabilisation Research
Work Request: 744
Sample Number: 20-744E
Date Sampled: 23/07/2020
Dates Tested: 31/07/2020 - 12/08/2020
Sample Location: **PT 5 - 1 and 3 - 65/35**
Lot No: **Pavement Type 5**
Sub Lot No: **1 and 3 65/35**

Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	59.0		
Plastic Limit (%)	28.8		
Plasticity Index (%)	**30.2**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	10.0		

Material Test Report

Report Number:	**BTK 20018-5**
Issue Number:	3 - *This version supersedes all previous issues*
Reissue Reason:	*Change 744H to 65/35*
Date Issued:	26/08/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Hybrid Pavement Stabilisation Research
Work Request:	744
Sample Number:	20-744F
Date Sampled:	23/07/2020
Dates Tested:	31/07/2020 - 31/07/2020
Sample Location:	**PT6 - 1 and 3 - 50/50**
Lot No:	**Pavement Type 6**
Sub Lot No:	**1 and 3 50/50**

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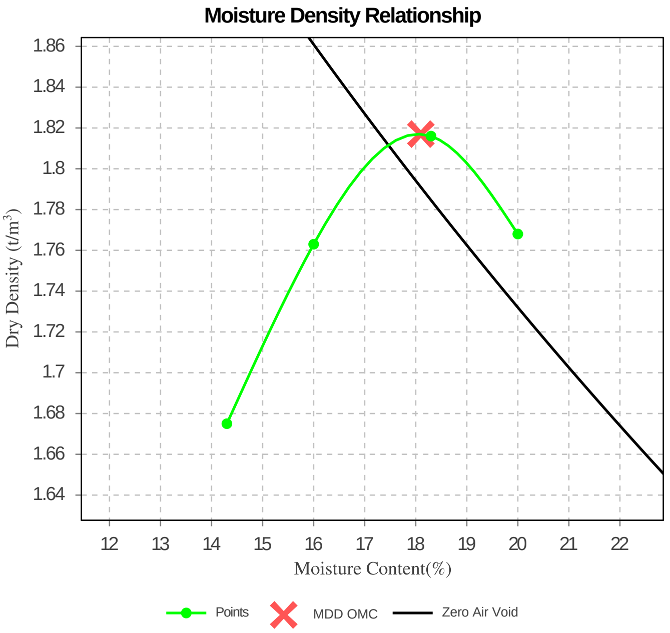
Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	1.82
Optimum Moisture Content (%)	18.0
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Vis/Tac
Curing Hours	24



Material Test Report

Report Number: **BTK 20018-5**
Issue Number: 3 - *This version supersedes all previous issues*
Reissue Reason: *Change 744H to 65/35*
Date Issued: 26/08/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Hybrid Pavement Stabilisation Research
Work Request: 744
Sample Number: 20-744G
Date Sampled: 23/07/2020
Dates Tested: 31/07/2020 - 31/07/2020
Sampling Method: AS 1289.1.2.1 6.2 - Sampling from stockpiles
Sample Location: **PT7 - 1 and 4 - 80/20**
Lot No: **Pavement Type 7**
Sub Lot No: **1 and 4 80/20**

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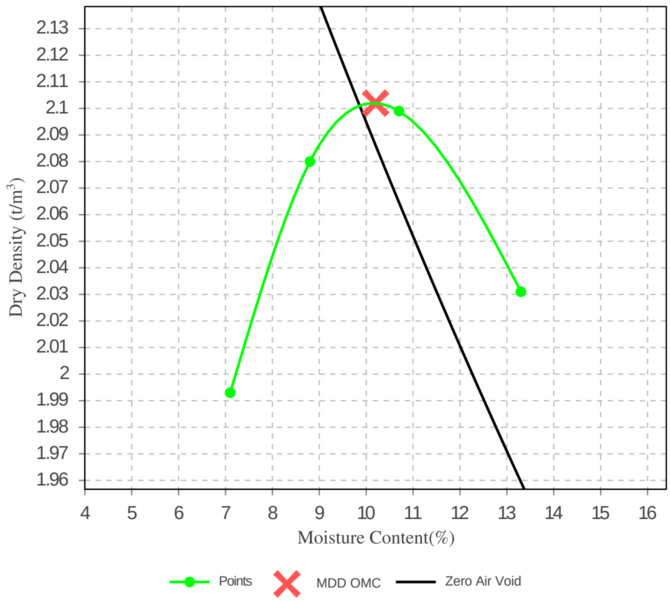
Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	2.10
Optimum Moisture Content (%)	10.0
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Vis/Tac
Curing Hours	24

Moisture Density Relationship



Material Test Report

Report Number: **BTK 20018-5**
Issue Number: 3 - *This version supersedes all previous issues*
Reissue Reason: *Change 744H to 65/35*
Date Issued: 26/08/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Hybrid Pavement Stabilisation Research
Work Request: 744
Sample Number: 20-744H
Date Sampled: 23/07/2020
Dates Tested: 31/07/2020 - 31/07/2020
Sample Location: **PT8 - 1 and 4 - 65/35**
Lot No: **Pavement Type 8**
Sub Lot No: **1 and 4 65/35**

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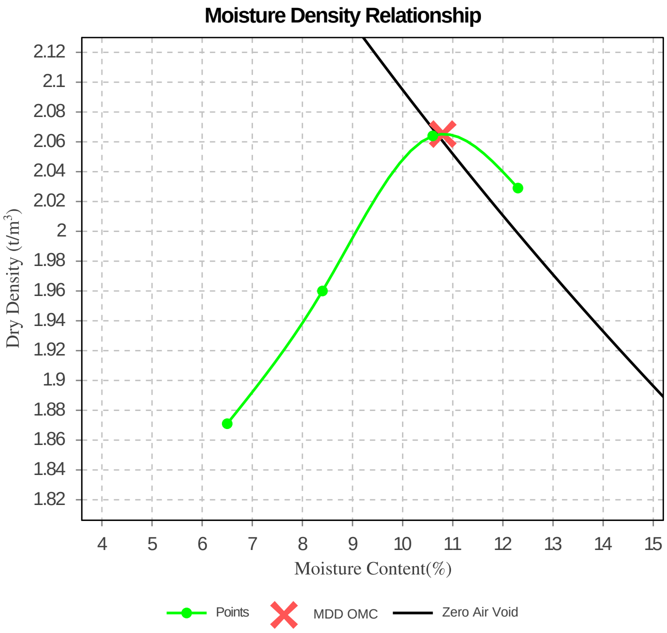
Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	2.07
Optimum Moisture Content (%)	11.0
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	24



Material Test Report

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Approved Signatory: James Dick
Manager
NATA Accredited Laboratory Number: 2851

Report Number: **BTK 20018-5**
Issue Number: 3 - *This version supersedes all previous issues*
Reissue Reason: *Change 744H to 65/35*
Date Issued: 26/08/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Hybrid Pavement Stabilisation Research
Work Request: 744
Sample Number: 20-744H
Date Sampled: 23/07/2020
Dates Tested: 31/07/2020 - 12/08/2020
Sample Location: **PT8 - 1 and 4 - 65/35**
Lot No: **Pavement Type 8**
Sub Lot No: **1 and 4 65/35**

Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	32.0		
Plastic Limit (%)	23.0		
Plasticity Index (%)	**9.0**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	6.6		

Material Test Report

Report Number: **BTK 20018-5**
Issue Number: 3 - *This version supersedes all previous issues*
Reissue Reason: *Change 744H to 65/35*
Date Issued: 26/08/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Hybrid Pavement Stabilisation Research
Work Request: 744
Sample Number: 20-744I
Date Sampled: 23/07/2020
Dates Tested: 31/07/2020 - 31/07/2020
Sample Location: **PT9 - 1 and 4 - 50/50**
Lot No: **Pavement Type 9**
Sub Lot No: **1 and 4 50/50**

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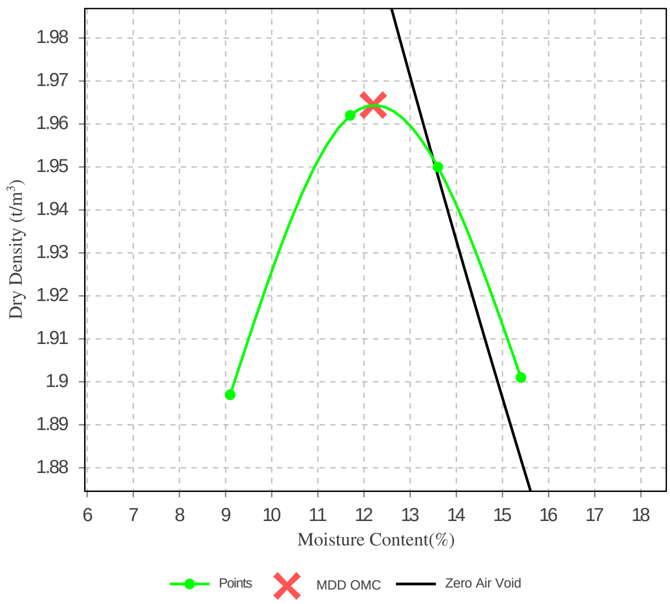
Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	1.96
Optimum Moisture Content (%)	12.0
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	24

Moisture Density Relationship



Material Test Report

Report Number: **BTK 20018-16**
Issue Number: 1
Date Issued: 07/10/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 815
Sample Number: 20-815A
Date Sampled: 24/08/2020
Dates Tested: 30/09/2020 - 06/10/2020
Sampling Method: Sampled by Client
The results apply to the sample as received
Sample Location: **Pavement Type 1**
Lot No: **Raw Material 1 and 2 80/20**

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Approved Signatory: Daniel French
Senior Technical Officer
NATA Accredited Laboratory Number: 2851

Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	36.4		
Plastic Limit (%)	15.6		
Plasticity Index (%)	**20.8**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	6.0		

Material Test Report

Report Number:	**BTK 20018-16**
Issue Number:	1
Date Issued:	07/10/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	815
Sample Number:	20-815B
Date Sampled:	24/08/2020
Dates Tested:	30/09/2020 - 05/10/2020
Sampling Method:	Sampled by Client *The results apply to the sample as received*
Sample Location:	**Pavement Type 3**
Lot No:	**Raw Material 1 and 2 50/50**

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Senior Technical Officer

NATA Accredited Laboratory Number: 2851

Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	74.0		
Plastic Limit (%)	32.8		
Plasticity Index (%)	**41.2**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	16.6		

Material Test Report

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Approved Signatory: Daniel French
Senior Technical Officer
NATA Accredited Laboratory Number: 2851

Report Number: **BTK 20018-16**
Issue Number: 1
Date Issued: 07/10/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 815
Sample Number: 20-815C
Date Sampled: 24/08/2020
Dates Tested: 30/09/2020 - 06/10/2020
Sampling Method: Sampled by Client
The results apply to the sample as received
Sample Location: **Pavement Type 4**
Lot No: **Raw Material 1 and 3 80/20**

Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	38.2		
Plastic Limit (%)	16.4		
Plasticity Index (%)	**21.8**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Air Dried		
Linear Shrinkage (%)	10.0		

Material Test Report

Report Number:	**BTK 20018-16**
Issue Number:	1
Date Issued:	07/10/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	815
Sample Number:	20-815D
Date Sampled:	24/08/2020
Dates Tested:	30/09/2020 - 06/10/2020
Sampling Method:	Sampled by Client *The results apply to the sample as received*
Sample Location:	**Pavement Type 6**
Lot No:	**Raw Matrial 1 and 3 50/50**

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Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	61.0		
Plastic Limit (%)	30.2		
Plasticity Index (%)	**30.8**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried / Air Dried		
Linear Shrinkage (%)	12.0		

Material Test Report

Report Number:	**BTK 20018-16**
Issue Number:	1
Date Issued:	07/10/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	815
Sample Number:	20-815E
Date Sampled:	24/08/2020
Dates Tested:	30/09/2020 - 06/10/2020
Sampling Method:	Sampled by Client *The results apply to the sample as received*
Sample Location:	**Pavement Type 7**
Lot No:	**Raw Materials 1 and 4 80/20**

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Senior Technical Officer

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Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	25.2		
Plastic Limit (%)	16.4		
Plasticity Index (%)	**8.8**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	3.4		

Material Test Report

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Senior Technical Officer
NATA Accredited Laboratory Number: 2851

Report Number:	**BTK 20018-16**
Issue Number:	1
Date Issued:	07/10/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	815
Sample Number:	20-815F
Date Sampled:	24/08/2020
Dates Tested:	30/09/2020 - 06/10/2020
Sampling Method:	Sampled by Client *The results apply to the sample as received*
Sample Location:	**Pavement Type 9**
Lot No:	**Raw Material 1 and 4 50/50**

Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	36.0		
Plastic Limit (%)	21.4		
Plasticity Index (%)	**14.6**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	6.6		

Appendix D:

Laboratory Test Reports, Testing Phase 3a – Lime/Cement/Flyash Triple Blends

Material Test Report

Report Number:	**BTK 20018-6**
Issue Number:	3 - *This version supersedes all previous issues*
Reissue Reason:	*Edit Pavement Type*
Date Issued:	08/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	747
Sample Number:	20-747B
Date Sampled:	20/07/2020
Dates Tested:	31/07/2020 - 17/08/2020
Sampling Method:	AS 1289.1.2.1 6.2 - Sampling from stockpiles
Sample Location:	**Pavement Type 1, Depth: 5% Blend**
Lot No:	**Raw Material 1 and 2 Ratio 80/20**
Material:	Research Blends

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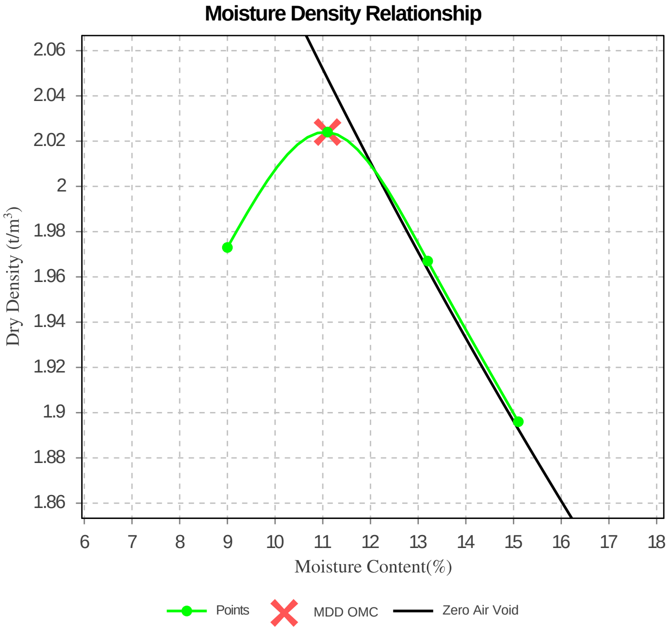
Approved Signatory: Daniel French
Senior Technical Officer
NATA Accredited Laboratory Number: 2851

Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	51.0		
Plastic Limit (%)	49.4		
Plasticity Index (%)	**1.6**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	2.2		

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	2.02
Optimum Moisture Content (%)	11.0
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	0.2



Material Test Report

Report Number:	**BTK 20018-6**
Issue Number:	3 - *This version supersedes all previous issues*
Reissue Reason:	*Edit Pavement Type*
Date Issued:	08/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	747
Sample Number:	20-747E
Date Sampled:	20/07/2020
Dates Tested:	31/07/2020 - 17/08/2020
Sampling Method:	AS 1289.1.2.1 6.2 - Sampling from stockpiles
Sample Location:	**Pavement Type 2, Depth: 5% Blend**
Lot No:	**Raw Material 1 and 2 Ratio 65/35**
Material:	Research Blends

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NATA WORLD RECOGNISED ACCREDITATION

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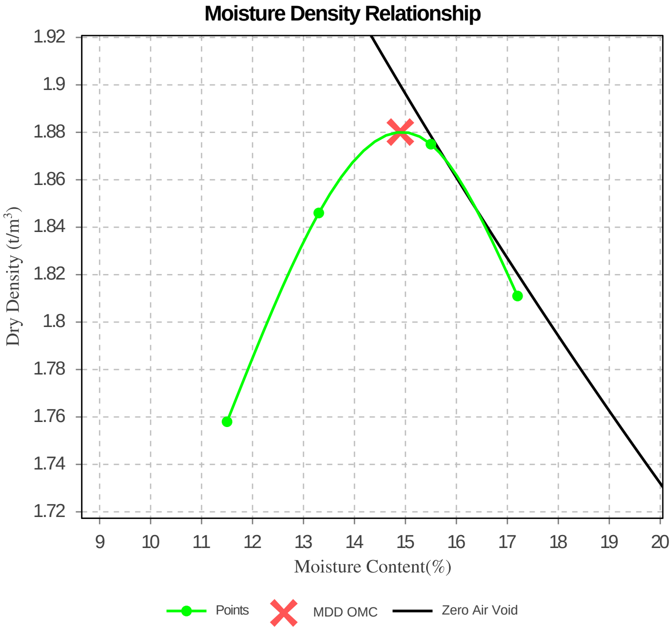
Approved Signatory: Daniel French
Senior Technical Officer

NATA Accredited Laboratory Number: 2851

Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	51.2		
Plastic Limit (%)	46.6		
Plasticity Index (%)	**4.6**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	4.0		

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	1.88
Optimum Moisture Content (%)	15.0
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	0.2



Material Test Report

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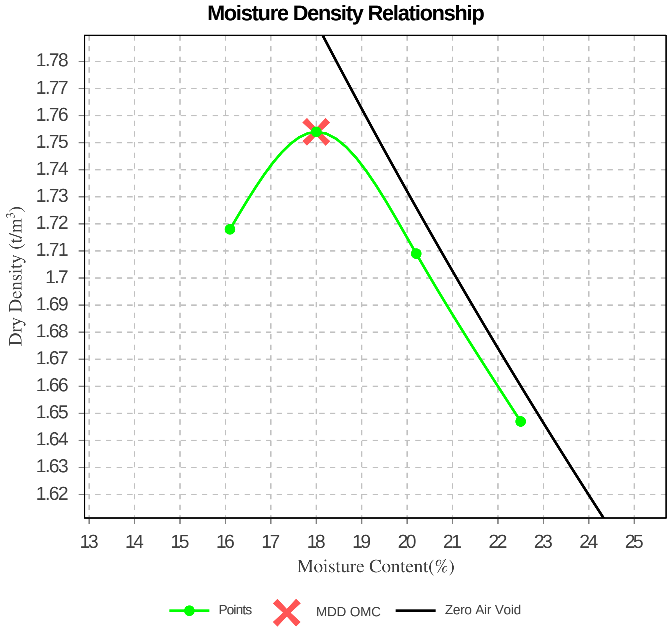
Approved Signatory: Daniel French
Senior Technical Officer
NATA Accredited Laboratory Number: 2851

Report Number:	**BTK 20018-6**
Issue Number:	3 - *This version supersedes all previous issues*
Reissue Reason:	*Edit Pavement Type*
Date Issued:	08/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	747
Sample Number:	20-747H
Date Sampled:	20/07/2020
Dates Tested:	31/07/2020 - 17/08/2020
Sampling Method:	AS 1289.1.2.1 6.2 - Sampling from stockpiles
Sample Location:	**Pavement Type 3, Depth: 5% Blend**
Lot No:	**Raw Blends 1 and 2 Ratio 50/50**
Material:	Research Blends

Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	53.6		
Plastic Limit (%)	45.0		
Plasticity Index (%)	**8.6**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	5.4		

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	1.75
Optimum Moisture Content (%)	18.0
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	0.2



Material Test Report

Report Number: **BTK 20018-6**
Issue Number: 3 - *This version supersedes all previous issues*
Reissue Reason: *Edit Pavement Type*
Date Issued: 08/09/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 747
Date Sampled: 20/07/2020
Dates Tested: 31/07/2020 - 01/09/2020
Lot Number: Laboratory Testing Phase 3A
Material: Research Blends

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Approved Signatory: Daniel French
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NATA Accredited Laboratory Number: 2851

Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-747A	20-747B	20-747C	20-747D		
Date Sampled	20/07/2020	20/07/2020	20/07/2020	20/07/2020		
Date Tested	01/09/2020	01/09/2020	01/09/2020	01/09/2020		
Sample Location	Pavement Type 1	Pavement Type 1	Pavement Type 1	Pavement Type 2		
Sample Depth	3% Blend	5% Blend	7% Blend	3% Blend		
Material	Research Blends	Research Blends	Research Blends	Research Blends		
Lot Number	Raw Material 1 and 2 Ratio 80/20	Raw Material 1 and 2 Ratio 80/20	Raw Material 1 and 2 Ratio 80/20	Raw Material 1 and 2 Ratio 65/35		
Sample Type	Laboratory Mixed	Laboratory Mixed	Laboratory Mixed	Laboratory Mixed		
Mass Retained 19.0mm Sieve (%)	0	0	0	0		
Curing Details	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**		
Condition After Curing	Moist	Moist	Moist	Moist		
Method of Addition	Laboratory Mix	Laboratory Mix	Laboratory Mix	Laboratory Mix		
Elapsed Time for Binder (Hrs:Mins)	0:45	0:48	0:45	0:48		
Additive Source	Client Supplied	Client Supplied	Client Supplied	Client Supplied		
Additive Type	30:40:30 Lime Cement Flyash	30:40:30 Lime Cement Flyash	30:40:30 Lime Cement Flyash	40:40:20 Lime Cement Flyash		
ATIC Registration Number	ATIC-059, ATIC-118, ATIC-069	ATIC-059, ATIC-118, ATIC-069	ATIC-059, ATIC-118, ATIC-069	ATIC-059, ATIC-118, ATIC-069		
Additive Content (%)	3%	5%	7%	3%		
Target Moisture Content (%)	11.0	11.1	11.1	11.1		
Moisture Content (%)	10.6	10.8	10.1	11.4		
Capped 1	No	No	No	No		
Capped 2	No	No	No	No		
Capped 3	No	No	No	No		
Alternate Compaction Method	Standard	Standard	Standard	Standard		
Alternate Compaction Layers	3	3	3	3		
Target Dry Density (t/m^3)	2.02	2.02	2.02	2.02		
Dry Density 1 (t/m^3)	2.00	2.01	2.04	1.99		
Dry Density 2 (t/m^3)	1.99	2.01	2.01	2.01		
Dry Density 3 (t/m^3)	2.00	2.01	2.01	2.01		
Laboratory Density Ratio (%)	99	99	100	99		
Laboratory Moisture Ratio (%)	96	97	91	103		
UCS Cylinder 1 (MPa)	1.7	1.4	2.4	0.7		
UCS Cylinder 2 (MPa)	1.7	1.9	2.0	0.6		
UCS Cylinder 3 (MPa)	1.2	2.1	2.4	0.5		
UCS Average (MPa)	**1.5**	**1.8**	**2.3**	**0.6**		
Remarks	**	**	**	**		

Material Test Report

Report Number:	**BTK 20018-6**
Issue Number:	3 - *This version supersedes all previous issues*
Reissue Reason:	*Edit Pavement Type*
Date Issued:	08/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	747
Date Sampled:	20/07/2020
Dates Tested:	31/07/2020 - 01/09/2020
Lot Number:	Laboratory Testing Phase 3A
Material:	Research Blends

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Approved Signatory: Daniel French
Senior Technical Officer

NATA Accredited Laboratory Number: 2851

Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-747E	20-747F	20-747G	20-747H		
Date Sampled	20/07/2020	20/07/2020	20/07/2020	20/07/2020		
Date Tested	01/09/2020	01/09/2020	01/09/2020	01/09/2020		
Sample Location	Pavement Type 2	Pavement Type 2	Pavement Type 3	Pavement Type 3		
Sample Depth	5% Blend	7% Blend	3% Blend	5% Blend		
Material	Research Blends	Research Blends	Research Blends	Research Blends		
Lot Number	Raw Material 1 and 2 Ratio 65/35	Raw Material 1 and 2 Ratio 65/35	Raw Material 1 and 2 Ratio 50/50	Raw Blends 1 and 2 Ratio 50/50		
Sample Type	Laboratory Mixed	Laboratory Mixed	Laboratory Mixed	Laboratory Mixed		
Mass Retained 19.0mm Sieve (%)	0	0	0	0		
Curing Details	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**		
Condition After Curing	Moist	Moist	Moist	Moist		
Method of Addition	Laboratory Mix	Field Mix	Laboratory Mix	Laboratory Mix		
Elapsed Time for Binder (Hrs:Mins)	0:48	0:58	0:50	0:45		
Additive Source	Client Supplied	Client Supplied	Client Supplied	Client Supplied		
Additive Type	40:40:20 Lime Cement Flyash	40:40:20 Lime Cement Flyash	50:30:20 Lime Cement Flyash	50:30:20 Lime Cement Flyash		
ATIC Registration Number	ATIC-059, ATIC-118, ATIC-069	ATIC-059, ATIC-118, ATIC-069	ATIC-059, ATIC-118, ATIC-069	ATIC-059, ATIC-118, ATIC-069		
Additive Content (%)	5%	7%	3%	5%		
Target Moisture Content (%)	14.9	14.9	14.9	18.0		
Moisture Content (%)	14.5	14.1	14.4	18.3		
Capped 1	No	No	No	No		
Capped 2	No	No	No	No		
Capped 3	No	No	No	No		
Alternate Compaction Method	Standard	Standard	Standard	Standard		
Alternate Compaction Layers	3	3	3	3		
Target Dry Density (t/m^3)	1.88	1.88	1.88	1.75		
Dry Density 1 (t/m^3)	1.84	1.81	1.83	1.73		
Dry Density 2 (t/m^3)	1.84	1.79	1.84	1.75		
Dry Density 3 (t/m^3)	1.83	1.81	1.83	1.75		
Laboratory Density Ratio (%)	98	96	98	99		
Laboratory Moisture Ratio (%)	97	95	97	102		
UCS Cylinder 1 (MPa)	1.3	1.9	0.3	0.4		
UCS Cylinder 2 (MPa)	1.6	1.3	0.2	0.6		
UCS Cylinder 3 (MPa)	1.6	1.8	0.3	0.7		
UCS Average (MPa)	**1.5**	**1.7**	**0.3**	**0.6**		
Remarks	**	**	**	**		

Material Test Report

Report Number: **BTK 20018-6**
Issue Number: 3 - *This version supersedes all previous issues*
Reissue Reason: *Edit Pavement Type*
Date Issued: 08/09/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 747
Date Sampled: 20/07/2020
Dates Tested: 31/07/2020 - 01/09/2020
Lot Number: Laboratory Testing Phase 3A
Material: Research Blends

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Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-747I					
Date Sampled	20/07/2020					
Date Tested	01/09/2020					
Sample Location	Pavement Type 3					
Sample Depth	7% Blend					
Material	Research Blends					
Lot Number	Raw Material 1 and 2 Ratio 50/50					
Sample Type	Laboratory Mixed					
Mass Retained 19.0mm Sieve (%)	0					
Curing Details	**28 Days Normal Curing (23 Deg. C) Rel. Hum. 100 Temp. 24 Room°C**					
Condition After Curing	Moist					
Method of Addition	Laboratory Mix					
Elapsed Time for Binder (Hrs:Mins)	0:48					
Additive Source	Client Supplied					
Additive Type	50:30:20 Lime Cement Flyash					
ATIC Registration Number	ATIC-059, ATIC-118, ATIC-069					
Additive Content (%)	7%					
Target Moisture Content (%)	18.0					
Moisture Content (%)	18.6					
Capped 1	No					
Capped 2	No					
Capped 3	No					
Alternate Compaction Method	Standard					
Alternate Compaction Layers	3					
Target Dry Density (t/m^3)	1.75					
Dry Density 1 (t/m^3)	1.73					
Dry Density 2 (t/m^3)	1.74					
Dry Density 3 (t/m^3)	1.74					
Laboratory Density Ratio (%)	99					
Laboratory Moisture Ratio (%)	103					
UCS Cylinder 1 (MPa)	1.2					
UCS Cylinder 2 (MPa)	1.4					
UCS Cylinder 3 (MPa)	1.2					
UCS Average (MPa)	**1.3**					
Remarks	**					

Material Test Report

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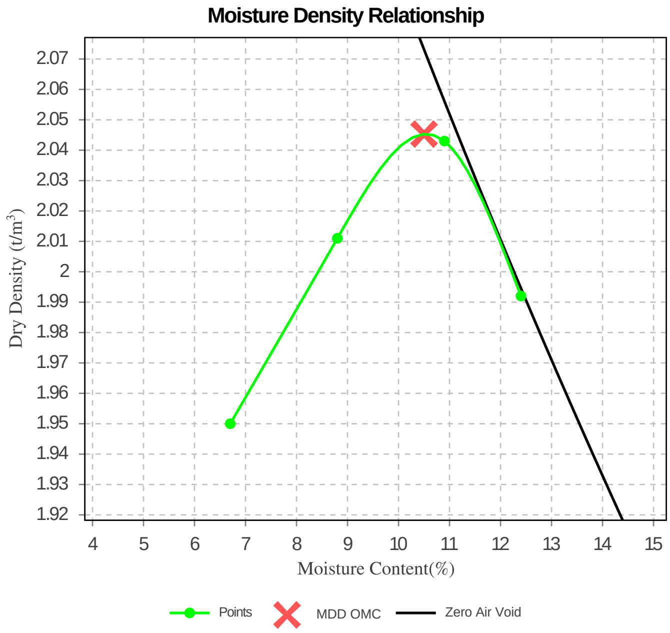
Approved Signatory: Daniel French
Senior Technical Officer
NATA Accredited Laboratory Number: 2851

Report Number:	**BTK 20018-7**
Issue Number:	1
Date Issued:	08/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	752
Sample Number:	20-752B
Date Sampled:	20/07/2020
Dates Tested:	05/08/2020 - 21/08/2020
Sampling Method:	AS 1289.1.2.1 6.2 - Sampling from stockpiles
Sample Location:	**Pavement Type 4, Depth: 5% Blend**
Lot No:	**Raw Material 1 and 3 Ratio 80/20**
Material:	Research Blends

Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	55.2		
Plastic Limit (%)	48.0		
Plasticity Index (%)	**7.2**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	5.4		

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	2.05
Optimum Moisture Content (%)	10.5
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	0.2



Material Test Report

Report Number:	**BTK 20018-7**
Issue Number:	1
Date Issued:	08/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	752
Sample Number:	20-752E
Date Sampled:	20/07/2020
Dates Tested:	05/08/2020 - 21/08/2020
Sampling Method:	AS 1289.1.2.1 6.2 - Sampling from stockpiles
Sample Location:	**Pavement Type 5, Depth: 5% Blend**
Lot No:	**Raw Material 1 and 3 Ratio 65/35**
Material:	Research Blends

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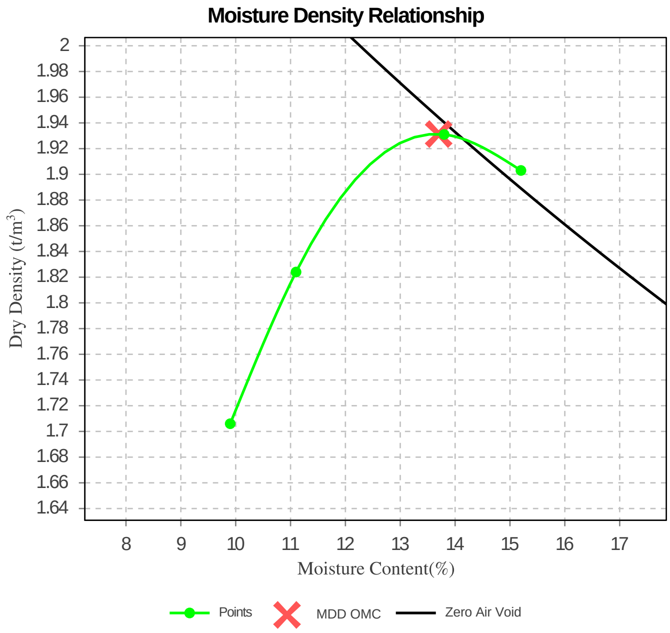
Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	53.8		
Plastic Limit (%)	48.0		
Plasticity Index (%)	**5.8**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	4.6		

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	1.93
Optimum Moisture Content (%)	13.5
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	0.2



Material Test Report

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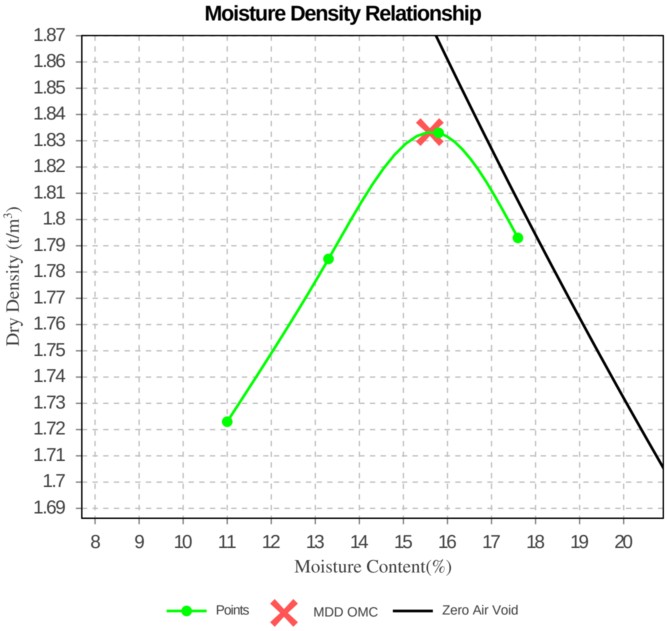
Report Number:	**BTK 20018-7**
Issue Number:	1
Date Issued:	08/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	752
Sample Number:	20-752H
Date Sampled:	20/07/2020
Dates Tested:	05/08/2020 - 04/09/2020
Sampling Method:	AS 1289.1.2.1 6.2 - Sampling from stockpiles
Site Selection:	Selected by Client
Sample Location:	**Pavement Type 6, Depth: 5% Blend**
Lot No:	**Raw Material 1 and 3 Ratio 50/50**
Material:	Research Blends

Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	51.0		
Plastic Limit (%)	48.4		
Plasticity Index (%)	**2.6**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	3.4		

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	1.83
Optimum Moisture Content (%)	15.5
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	0.2



Material Test Report

Report Number: **BTK 20018-7**
Issue Number: 1
Date Issued: 08/09/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 752
Dates Tested: 05/08/2020 - 04/09/2020
Site Selection: Selected by Client
Lot Number: Laboratory Testing Phase 3A
Material: Research Blends

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Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-752A	20-752B	20-752C	20-752D		
Date Sampled	20/07/2020	20/07/2020	20/07/2020	20/07/2020		
Date Tested	04/09/2020	04/09/2020	04/09/2020	04/09/2020		
Sample Location	Pavement Type 4	Pavement Type 4	Pavement Type 4	Pavement Type 5		
Sample Depth	3% Blend	5% Blend	7% Blend	3% Blend		
Material	Research Blends	Research Blends	Research Blends	Research Blends		
Lot Number	Raw Material 1 and 3 Ratio 80/20	Raw Material 1 and 3 Ratio 80/20	Raw Material 1 and 3 Ratio 80/20	Raw Material 1 and 3 Ratio 65/35		
Sample Type	Laboratory Mixed	Laboratory Mixed	Laboratory Mixed	Laboratory Mixed		
Mass Retained 19.0mm Sieve (%)	0	0	0	0		
Curing Details	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**		
Condition After Curing	Moist	Moist	Moist	Moist		
Method of Addition	Laboratory Mix	Laboratory Mix	Laboratory Mix	Laboratory Mix		
Elapsed Time for Binder (Hrs:Mins)	0:47	0:42	0:52	0:45		
Additive Source	Client Supplied	Client Supplied	Client Supplied	Client Supplied		
Additive Type	30:40:30 Lime Cement Flyash	30:40:30 Lime Cement Flyash	30:40:30 Lime Cement Flyash	40:40:20 Lime Cement Flyash		
ATIC Registration Number	ATIC- 059, ATIC-118, ATIC-069	ATIC-069, ATIC-118, ATIC-069	ATIC-059, ATIC-118, ATIC-069	ATIC-059, ATIC-118, ATIC-069		
Additive Content (%)	3%	5%	7%	3%		
Target Moisture Content (%)	10.5	10.5	10.5	10.5		
Moisture Content (%)	9.9	10.2	10.0	13.6		
Capped 1	No	No	No	No		
Capped 2	No	No	No	No		
Capped 3	No	No	No	No		
Alternate Compaction Method	Standard	Standard	Standard	Standard		
Alternate Compaction Layers	3	3	3	3		
Target Dry Density (t/m^3)	2.05	2.05	2.05	2.05		
Dry Density 1 (t/m^3)	2.06	2.04	2.05	1.94		
Dry Density 2 (t/m^3)	2.08	2.05	2.07	1.93		
Dry Density 3 (t/m^3)	2.05	2.04	2.05	1.92		
Laboratory Density Ratio (%)	101	100	101	94		
Laboratory Moisture Ratio (%)	94	97	95	130		
UCS Cylinder 1 (MPa)	1.9	2.2	3.3	1.2		
UCS Cylinder 2 (MPa)	1.8	1.7	3.1	1.2		
UCS Cylinder 3 (MPa)	2.0	2.2	3.0	1.0		
UCS Average (MPa)	**1.9**	**2.0**	**3.1**	**1.1**		
Remarks	**	**	**	**		

Material Test Report

Report Number:	**BTK 20018-7**
Issue Number:	1
Date Issued:	08/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	752
Dates Tested:	05/08/2020 - 04/09/2020
Site Selection:	Selected by Client
Lot Number:	Laboratory Testing Phase 3A
Material:	Research Blends

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Approved Signatory: Daniel French
Senior Technical Officer

NATA Accredited Laboratory Number: 2851

Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-752E	20-752F	20-752G	20-752H		
Date Sampled	20/07/2020	20/07/2020	20/07/2020	20/07/2020		
Date Tested	04/09/2020	04/09/2020	04/09/2020	04/09/2020		
Sample Location	Pavement Type 5	Pavement Type 5	Pavement Type 6	Pavement Type 6		
Sample Depth	5% Blend	7% Blend	3% Blend	5% Blend		
Material	Research Blends	Research Blends	Research Blends	Research Blends		
Lot Number	Raw Material 1 and 3 Ratio 65/35	Raw Material 1 and 3 Ratio 65/35	Raw Material 1 and 3 Ratio 50/50	Raw Material 1 and 3 Ratio 50/50		
Sample Type	Laboratory Mixed	Laboratory Mixed	Laboratory Mixed	Laboratory Mixed		
Mass Retained 19.0mm Sieve (%)	0	0	0	0		
Curing Details	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**		
Condition After Curing	Moist	Moist	Moist	Moist		
Method of Addition	Laboratory Mix	Laboratory Mix	Laboratory Mix	Laboratory Mix		
Elapsed Time for Binder (Hrs:Mins)	0:47	0:53	0:45	0:45		
Additive Source	Client Supplied	Client Supplied	Client Supplied	Client Supplied		
Additive Type	40:40:20 Lime Cement Flyash	40:40:20 Lime Cement Flyash	50:30:20 Lime Cement Flyash	50:30:20 Lime Cement Flyash		
ATIC Registration Number	ATIC-059, ATIC-118, ATIC 069	ATIC-059, ATIC-118, ATIC-069	ATIC-059, ATIC-118, ATIC-069	ATIC- 059, ATIC-118, ATIC-069		
Additive Content (%)	5%	7%	3%	5%		
Target Moisture Content (%)	13.7	13.7	13.7	15.6		
Moisture Content (%)	13.7	13.3	15.1	15.5		
Capped 1	No	No	No	No		
Capped 2	No	No	No	No		
Capped 3	No	No	No	No		
Alternate Compaction Method	Standard	Standard	Standard	Standard		
Alternate Compaction Layers	3	3	3	3		
Target Dry Density (t/m^3)	1.93	1.93	1.93	1.83		
Dry Density 1 (t/m^3)	1.94	1.93	1.82	1.83		
Dry Density 2 (t/m^3)	1.92	1.92	1.84	1.82		
Dry Density 3 (t/m^3)	1.93	1.94	1.84	1.81		
Laboratory Density Ratio (%)	100	100	95	99		
Laboratory Moisture Ratio (%)	100	97	110	99		
UCS Cylinder 1 (MPa)	1.9	2.0	0.8	1.8		
UCS Cylinder 2 (MPa)	2.0	1.9	0.6	1.4		
UCS Cylinder 3 (MPa)	1.8	1.7	0.5	1.6		
UCS Average (MPa)	**1.9**	**1.9**	**0.6**	**1.6**		
Remarks	**	**	**	**		

Material Test Report

Report Number: **BTK 20018-7**
Issue Number: 1
Date Issued: 08/09/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 752
Dates Tested: 05/08/2020 - 04/09/2020
Site Selection: Selected by Client
Lot Number: Laboratory Testing Phase 3A
Material: Research Blends

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NATA WORLD RECOGNISED ACCREDITATION

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Approved Signatory: Daniel French
Senior Technical Officer

NATA Accredited Laboratory Number: 2851

Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-752I					
Date Sampled	20/07/2020					
Date Tested	04/09/2020					
Sample Location	Pavement Type 6					
Sample Depth	7% Blend					
Material	Research Blends					
Lot Number	Raw Material 1 and 3 Ratio 50/30/20					
Sample Type	Laboratory Mixed					
Mass Retained 19.0mm Sieve (%)	0					
Curing Details	**28 Days Normal Curing (23 Deg. C)**					
Condition After Curing	Moist					
Method of Addition	Laboratory Mix					
Elapsed Time for Binder (Hrs:Mins)	0:45					
Additive Source	Client Supplied					
Additive Type	50:30:20 Lime Cement Flyash					
ATIC Registration Number	ATIC-059, ATIC-118, ATIC-069					
Additive Content (%)	7%					
Target Moisture Content (%)	15.6					
Moisture Content (%)	15.1					
Capped 1	No					
Capped 2	No					
Capped 3	No					
Alternate Compaction Method	Standard					
Alternate Compaction Layers	3					
Target Dry Density (t/m^3)	1.83					
Dry Density 1 (t/m^3)	1.84					
Dry Density 2 (t/m^3)	1.84					
Dry Density 3 (t/m^3)	1.84					
Laboratory Density Ratio (%)	100					
Laboratory Moisture Ratio (%)	97					
UCS Cylinder 1 (MPa)	1.2					
UCS Cylinder 2 (MPa)	1.4					
UCS Cylinder 3 (MPa)	1.4					
UCS Average (MPa)	**1.3**					
Remarks	**					

Material Test Report

Report Number:	**BTK 20018-8**
Issue Number:	1
Date Issued:	08/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	753
Sample Number:	20-753B
Date Sampled:	20/07/2020
Dates Tested:	05/08/2020 - 21/08/2020
Sampling Method:	AS 1289.1.2.1 6.2 - Sampling from stockpiles
Sample Location:	**Pavement Type 7, Depth: 5% Blend**
Lot No:	**Raw Material 1 and 4 Ratio 80/20**
Material:	Research Blends

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Senior Technical Officer

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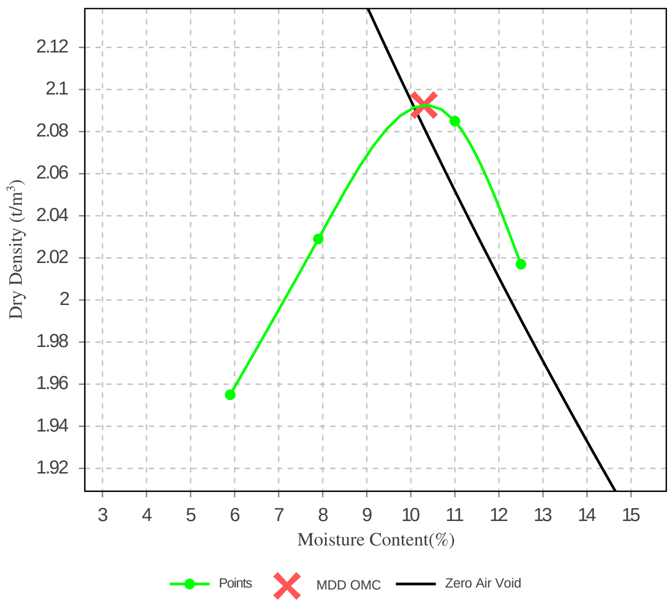
Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	27.2		
Plastic Limit (%)	19.8		
Plasticity Index (%)	**7.4**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	3.4		

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	2.09
Optimum Moisture Content (%)	10.5
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	0.2

Moisture Density Relationship



Material Test Report

Report Number:	**BTK 20018-8**
Issue Number:	1
Date Issued:	08/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd
	67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	753
Sample Number:	20-753E
Date Sampled:	20/07/2020
Dates Tested:	05/08/2020 - 27/08/2020
Sampling Method:	AS 1289.1.2.1 6.2 - Sampling from stockpiles
Sample Location:	**Pavement Type 8, Depth: 5% Blend**
Lot No:	**Raw Material 1 and 4 Ratio 65/35**
Material:	Research Blends

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Senior Technical Officer

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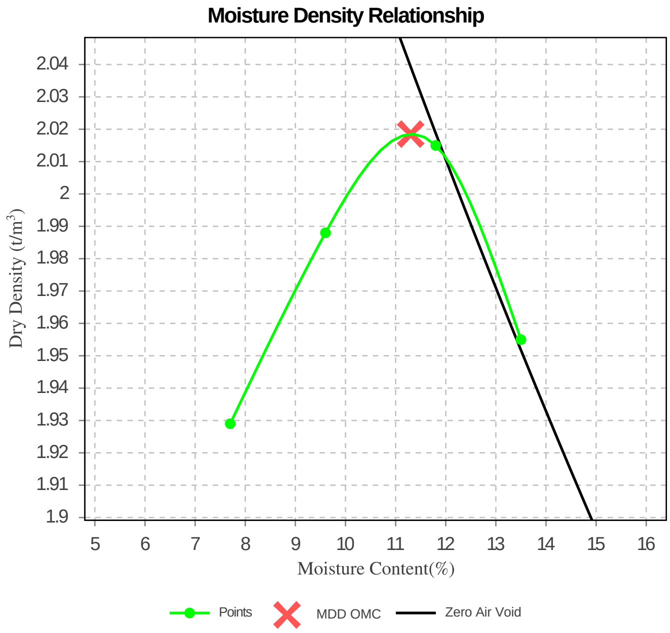
Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	40.2		
Plastic Limit (%)	36.4		
Plasticity Index (%)	**3.8**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	3.4		

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	2.02
Optimum Moisture Content (%)	11.5
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	0.2



Material Test Report

Report Number:	**BTK 20018-8**
Issue Number:	1
Date Issued:	08/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	753
Sample Number:	20-753H
Date Sampled:	20/07/2020
Dates Tested:	05/08/2020 - 27/08/2020
Sampling Method:	AS 1289.1.2.1 6.2 - Sampling from stockpiles
Sample Location:	**Pavement Type 9, Depth: 5% Blend**
Lot No:	**Raw Material 1 and 4 Ratio 50/50**
Material:	Research Blends

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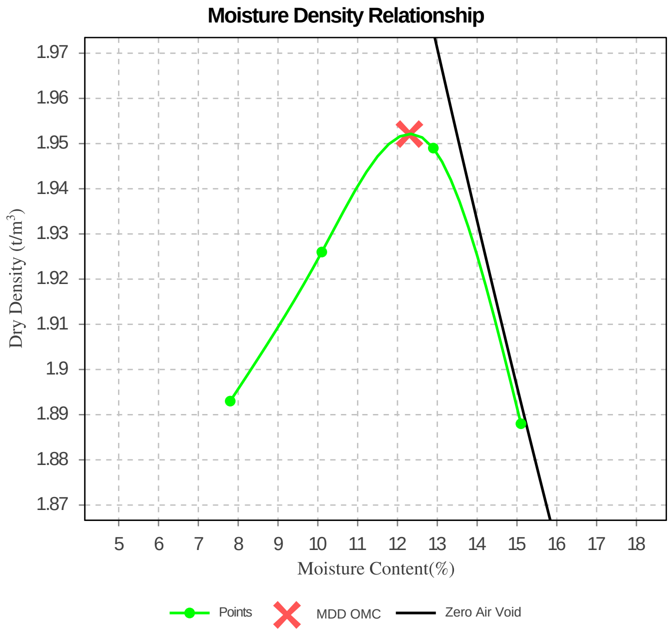
Approved Signatory: Daniel French
Senior Technical Officer

NATA Accredited Laboratory Number: 2851

Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	39.0		
Plastic Limit (%)	34.6		
Plasticity Index (%)	**4.4**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	4.0		

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	1.95
Optimum Moisture Content (%)	12.5
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	0.2



Material Test Report

Report Number: BTK 20018-8
Issue Number: 1
Date Issued: 08/09/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 753
Date Sampled: 20/07/2020
Dates Tested: 05/08/2020 - 04/09/2020
Site Selection: Selected by Client
Lot Number: Laboratory Testing Phase 3A

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NATA WORLD RECOGNISED ACCREDITATION

Approved Signatory: Daniel French
Senior Technical Officer
NATA Accredited Laboratory Number: 2851

Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-753A	20-753B	20-753C	20-753D		
Date Sampled	20/07/2020	20/07/2020	20/07/2020	20/07/2020		
Date Tested	04/09/2020	04/09/2020	04/09/2020	04/09/2020		
Sample Location	Pavement Type 7	Pavement Type 7	Pavement Type 7	Pavement Type 8		
Sample Depth	3 % Blend	5% Blend	7% Blend	3% Blend		
Material	Research Blends	Research Blends	Research Blends	Research Blends		
Lot Number	Raw Material 1 and 4 Ratio 80/20	Raw Material 1 and 4 Ratio 80/20	Raw Material 1 and 4 Ratio 80/20	Raw Material 1 and 4 Ratio 65/35		
Sample Type	Laboratory Mixed	Laboratory Mixed	Laboratory Mixed	Laboratory Mixed		
Mass Retained 19.0mm Sieve (%)	0	0	0	0		
Curing Details	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**		
Condition After Curing	Moist	Moist	Moist	Moist		
Method of Addition	Laboratory Mix	Laboratory Mix	Laboratory Mix	Laboratory Mix		
Elapsed Time for Binder (Hrs:Mins)	0:45	0:53	0:47	0:48		
Additive Source	Client Supplied	Client Supplied	Client Supplied	Client Supplied		
Additive Type	30:40:30 Lime Cement Flyash	30:40:30 Lime Cement Flyash	30:40:30 Lime Cement Flyash	40:40:20 Lime Cement Flyash		
ATIC Registration Number	ATIC-069, ATIC-118, ATIC-059	ATIC-059, ATIC-118, ATIC-069	ATIC-059, ATIC-118, ATIC-069	ATIC-059, ATIC-118, ATIC-069		
Additive Content (%)	3%	5%	7%	3%		
Target Moisture Content (%)	10.5	10.3	10.3	10.3		
Moisture Content (%)	10.3	10.3	10.2	9.7		
Capped 1	No	No	No	No		
Capped 2	No	No	No	No		
Capped 3	No	No	No	No		
Alternate Compaction Method	Standard	Standard	Standard	Standard		
Alternate Compaction Layers	3	3	3	3		
Target Dry Density (t/m^3)	2.09	2.09	2.09	2.09		
Dry Density 1 (t/m^3)	2.10	2.10	2.08	2.09		
Dry Density 2 (t/m^3)	2.11	2.09	2.09	2.10		
Dry Density 3 (t/m^3)	2.11	2.09	2.08	2.10		
Laboratory Density Ratio (%)	101	100	100	100		
Laboratory Moisture Ratio (%)	98	100	99	94		
UCS Cylinder 1 (MPa)	0.8	1.3	1.8	1.0		
UCS Cylinder 2 (MPa)	0.8	1.4	2.1	1.0		
UCS Cylinder 3 (MPa)	0.9	1.3	1.6	1.1		
UCS Average (MPa)	**0.8**	**1.3**	**1.8**	**1.0**		
Remarks	**	**	**	**		

Material Test Report

Report Number: **BTK 20018-8**
Issue Number: 1
Date Issued: 08/09/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 753
Date Sampled: 20/07/2020
Dates Tested: 05/08/2020 - 04/09/2020
Site Selection: Selected by Client
Lot Number: Laboratory Testing Phase 3A

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Approved Signatory: Daniel French
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NATA Accredited Laboratory Number: 2851

Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-753E	20-753F	20-753G	20-753H		
Date Sampled	20/07/2020	20/07/2020	20/07/2020	20/07/2020		
Date Tested	04/09/2020	04/09/2020	04/09/2020	04/09/2020		
Sample Location	Pavement Type 8	Pavement Type 8	Pavent Type 9	Pavement Type 9		
Sample Depth	5% Blend	7% Blend	3% Blend	5% Blend		
Material	Research Blends	Research Blends	Research Blends	Research Blends		
Lot Number	Raw Material 1 and 4 Ratio 65/35	Raw Material 1 and 4 Ratio 65/35	Raw Material 1 and 4 Ratio 50/50	Raw Material 1 and 4 Ratio 50/50		
Sample Type	Laboratory Mixed	Laboratory Mixed	Laboratory Mixed	Laboratory Mixed		
Mass Retained 19.0mm Sieve (%)	0	0	0	0		
Curing Details	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**		
Condition After Curing	Moist	Moist	Moist	Moist		
Method of Addition	Laboratory Mix	Laboratory Mix	Laboratory Mix	Laboratory Mix		
Elapsed Time for Binder (Hrs:Mins)	0:45	0:42	0:45	0:50		
Additive Source	Client Supplied	Client Supplied	Client Supplied	Client Supplied		
Additive Type	40:40:20 Lime Cement Flyash	40:40:20 Lime Cement Flyash	50:30:20 Lime Cement Flyash	50:30:20 Lime Cement Flyash		
ATIC Registration Number	ATIC059, ATIC-118, ATIC-069	ATIC059, ATIC118, ATIC069	ATIC-059, ATIC118, ATIC-069	ATIC-059, ATIC-118, ATIC-069		
Additive Content (%)	5%	7%	3%	5%		
Target Moisture Content (%)	11.3	11.3	11.3	12.3		
Moisture Content (%)	11.3	10.8	11.0	12.2		
Capped 1	No	No	No	No		
Capped 2	No	No	No	No		
Capped 3	No	No	No	No		
Alternate Compaction Method	Standard	Standard	Standard	Standard		
Alternate Compaction Layers	3	3	3	3		
Target Dry Density (t/m^3)	2.02	2.02	2.02	1.95		
Dry Density 1 (t/m^3)	2.02	2.03	1.97	1.95		
Dry Density 2 (t/m^3)	2.02	2.04	1.96	1.95		
Dry Density 3 (t/m^3)	2.03	2.02	1.98	1.95		
Laboratory Density Ratio (%)	100	101	98	100		
Laboratory Moisture Ratio (%)	100	96	97	99		
UCS Cylinder 1 (MPa)	1.6	2.1	1.0	1.2		
UCS Cylinder 2 (MPa)	1.4	1.8	1.0	1.3		
UCS Cylinder 3 (MPa)	1.6	2.0	1.1	1.4		
UCS Average (MPa)	**1.5**	**2.0**	**1.0**	**1.3**		
Remarks	**	**	**	**		

Material Test Report

Report Number:	**BTK 20018-8**
Issue Number:	1
Date Issued:	08/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	753
Date Sampled:	20/07/2020
Dates Tested:	05/08/2020 - 04/09/2020
Site Selection:	Selected by Client
Lot Number:	Laboratory Testing Phase 3A

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Approved Signatory: Daniel French
Senior Technical Officer
NATA Accredited Laboratory Number: 2851

Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-753I					
Date Sampled	20/07/2020					
Date Tested	04/09/2020					
Sample Location	Pavement Type 9					
Sample Depth	7% Blend					
Material	Research Blends					
Lot Number	Raw Material 1 and 4 Ratio 50/50					
Sample Type	Laboratory Mixed					
Mass Retained 19.0mm Sieve (%)	0					
Curing Details	**28 Days Normal Curing (23 Deg. C)**					
Condition After Curing	Moist					
Method of Addition	Laboratory Mix					
Elapsed Time for Binder (Hrs:Mins)	0:47					
Additive Source	Client Supplied					
Additive Type	50:30:20 Lime Cement Flyash					
ATIC Registration Number	ATIC-059, ATIC-118, ATIC069					
Additive Content (%)	7%					
Target Moisture Content (%)	12.3					
Moisture Content (%)	12.3					
Capped 1	No					
Capped 2	No					
Capped 3	No					
Alternate Compaction Method	Standard					
Alternate Compaction Layers	3					
Target Dry Density (t/m^3)	1.95					
Dry Density 1 (t/m^3)	1.94					
Dry Density 2 (t/m^3)	1.96					
Dry Density 3 (t/m^3)	1.97					
Laboratory Density Ratio (%)	100					
Laboratory Moisture Ratio (%)	100					
UCS Cylinder 1 (MPa)	1.7					
UCS Cylinder 2 (MPa)	1.8					
UCS Cylinder 3 (MPa)	1.9					
UCS Average (MPa)	**1.8**					
Remarks	**					

Appendix E:

Laboratory Test Reports, Testing Phase 3b – Slag/Lime General Blends

Material Test Report

Report Number:	**BTK 20018-9**
Issue Number:	2 - *This version supersedes all previous issues*
Reissue Reason:	*MDR Applied*
Date Issued:	11/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	766
Sample Number:	20-766B
Date Sampled:	20/07/2020
Dates Tested:	11/08/2020 - 07/09/2020
Site Selection:	Selected by Client
Sample Location:	**Pavement 2, Depth: 5% Blend**
Lot No:	**Raw Blend 1 and 2 Ratio 65/35**
Material:	Research Blends

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Accredited for compliance with ISO/IEC 17025 - Testing

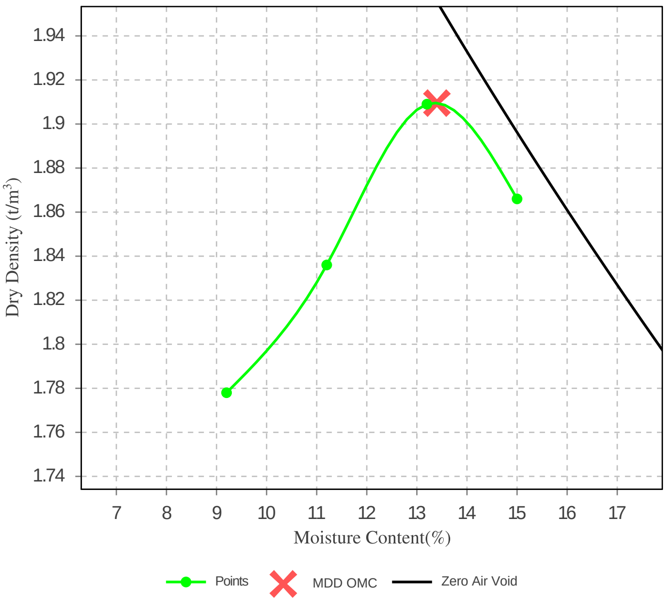
Approved Signatory: Aaron O'Donoghue
Senior Technical Officer
NATA Accredited Laboratory Number: 2851

Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	46.2		
Plastic Limit (%)	39.6		
Plasticity Index (%)	**6.6**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	6.0		

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	1.91
Optimum Moisture Content (%)	13.5
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	0.2

Moisture Density Relationship



Material Test Report

Report Number: **BTK 20018-9**
Issue Number: 2 - *This version supersedes all previous issues*
Reissue Reason: *MDR Applied*
Date Issued: 11/09/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 766
Dates Tested: 11/08/2020 - 10/09/2020
Lot Number: Laboratory Testing Phase 3B

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Approved Signatory: Aaron O'Donoghue
Senior Technical Officer
NATA Accredited Laboratory Number: 2851

Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-766A	20-766B	20-766C	20-766D		
Date Sampled	20/07/2020	20/07/2020	20/07/2020	20/07/2020		
Date Tested	10/09/2020	10/09/2020	10/09/2020	10/09/2020		
Sample Location	Pavement Type 1	Pavement 2	Pavement Type 3	Pavement Type 1		
Sample Depth	5% Blend	5% Blend	5% Blend	7%		
Material	Research Blends	Research Blends	Research Blends	Research Blends		
Lot Number	Raw Material 1 and 2 Ratio 80/20	Raw Blend 1 and 2 Ratio 65/35	Raw Material 1 and 2 Ratio 50/50	Raw Material 1 and 2 Ratio 80/20		
Sample Type	Field Mixed	Field Mixed	Field Mixed	Field Mixed		
Mass Retained 19.0mm Sieve (%)	0	0	0	0		
Curing Details	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**		
Condition After Curing	Moist	Moist	Moist	Moist		
Method of Addition	Laboratory Mix	Laboratory Mix	Laboratory Mix	Laboratory Mix		
Elapsed Time for Binder (Hrs:Mins)	0:05	0:05	0:05	0:05		
Additive Source	Client Supplied	Client Supplied	Client Supplied	Client Supplied		
Additive Type	60:40 Slag Lime	60:40 Slag Lime	60:40 Slag Lime	60:40 Slag Lime		
ATIC Registration Number	ATIC-140, ATIC- 059	ATIC-140, ATIC059	ATIC-140, ATIC-059	ATIC-140, ATIC-059		
Additive Content (%)	5%	5%	5%	7%		
Target Moisture Content (%)	13.5	13.4	13.4	13.4		
Moisture Content (%)	12.7	13.3	13.7	13.1		
Capped 1	No	No	No	No		
Capped 2	No	No	No	No		
Capped 3	No	No	No	No		
Alternate Compaction Method	Standard	Standard	Standard	Standard		
Alternate Compaction Layers	3	3	3	3		
Target Dry Density (t/m^3)	1.91	1.91	1.91	1.91		
Dry Density 1 (t/m^3)	1.92	1.91	1.91	1.92		
Dry Density 2 (t/m^3)	1.93	1.92	1.90	1.91		
Dry Density 3 (t/m^3)	1.92	1.91	1.91	1.92		
Laboratory Density Ratio (%)	101	100	100	100		
Laboratory Moisture Ratio (%)	94	99	102	98		
UCS Cylinder 1 (MPa)	2.8	1.1	0.8	3.6		
UCS Cylinder 2 (MPa)	3.3	1.3	0.6	3.1		
UCS Cylinder 3 (MPa)	2.6	1.3	0.7	3.2		
UCS Average (MPa)	**2.9**	**1.2**	**0.7**	**3.3**		
Remarks	**	**	**	**		

Material Test Report

Report Number: **BTK 20018-9**
Issue Number: 2 - *This version supersedes all previous issues*
Reissue Reason: *MDR Applied*
Date Issued: 11/09/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 766
Dates Tested: 11/08/2020 - 10/09/2020
Lot Number: Laboratory Testing Phase 3B

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Approved Signatory: Aaron O'Donoghue
Senior Technical Officer

NATA Accredited Laboratory Number: 2851

Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-766E	20-766F				
Date Sampled	20/07/2020	20/07/2020				
Date Tested	10/09/2020	10/09/2020				
Sample Location	Pavement Type 2	Pavement Type 3				
Sample Depth	7% Blend	7% Blend				
Material	Research Blends	Research Blends				
Lot Number	Raw Material 1 and 2 Ratio 65/35	Raw Material 1 and 2 Ratio 50/50				
Sample Type	Field Mixed	Laboratory Mixed				
Mass Retained 19.0mm Sieve (%)	0	0				
Curing Details	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**				
Condition After Curing	Moist	Moist				
Method of Addition	Laboratory Mix	Laboratory Mix				
Elapsed Time for Binder (Hrs:Mins)	0:05	0:10				
Additive Source	Client Supplied	Client Supplied				
Additive Type	60:40 Slag Lime	60:40 Slag Lime				
ATIC Registration Number	ATIC-140, ATIC-059	ATIC-140, ATIC-059				
Additive Content (%)	7%	7%				
Target Moisture Content (%)	13.4	13.4				
Moisture Content (%)	13.2	13.7				
Capped 1	No	No				
Capped 2	No	No				
Capped 3	No	No				
Alternate Compaction Method	Standard	Standard				
Alternate Compaction Layers	3	3				
Target Dry Density (t/m^3)	1.91	1.91				
Dry Density 1 (t/m^3)	1.91	1.89				
Dry Density 2 (t/m^3)	1.91	1.89				
Dry Density 3 (t/m^3)	1.92	1.91				
Laboratory Density Ratio (%)	100	99				
Laboratory Moisture Ratio (%)	98	102				
UCS Cylinder 1 (MPa)	1.9	0.8				
UCS Cylinder 2 (MPa)	1.9	1.0				
UCS Cylinder 3 (MPa)	2.1	1.0				
UCS Average (MPa)	**2.0**	**0.9**				
Remarks	**	**				

Material Test Report

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Approved Signatory: James Dick
Manager

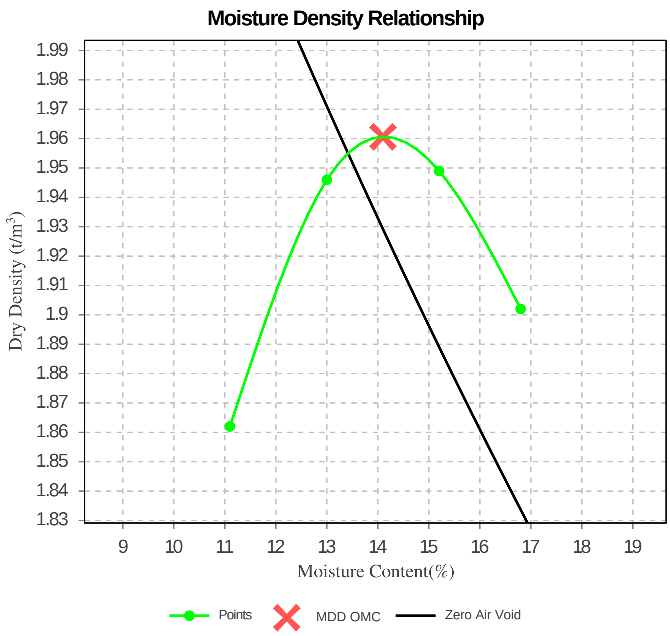
NATA Accredited Laboratory Number: 2851

Report Number:	**BTK 20018-10**
Issue Number:	1
Date Issued:	17/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	767
Sample Number:	20-767B
Date Sampled:	20/07/2020
Dates Tested:	11/08/2020 - 21/08/2020
Sample Location:	**Pavement Type 5, Depth: 5% Blend**
Lot No:	**Raw Material 1 and 3 Ratio 65/35**
Material:	Research Blends

Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	53.0		
Plastic Limit (%)	46.8		
Plasticity Index (%)	**6.2**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	4.6		

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	1.96
Optimum Moisture Content (%)	14.0
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	0.2



Material Test Report

Report Number: **BTK 20018-10**
Issue Number: 1
Date Issued: 17/09/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 767
Date Sampled: 20/07/2020
Dates Tested: 11/08/2020 - 10/09/2020
Site Selection: Selected by Client
Lot Number: Laboratory Testing Phase B

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Approved Signatory: James Dick
Manager
NATA Accredited Laboratory Number: 2851

Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-767A	20-767B	20-767C	20-767D		
Date Sampled	20/07/2020	20/07/2020	20/07/2020	20/07/2020		
Date Tested	10/09/2020	10/09/2020	10/09/2020	10/09/2020		
Sample Location	Pavement Type 4	Pavement Type 5	Pavement Type 6	Pavement Type 4		
Sample Depth	5% Blend	5% Blend	5% Blend	7% Blend		
Material	Research Blends	Research Blends	Research Blends	Research Blends		
Lot Number	Raw Blend 1 and 3 Ratio 80/20	Raw Material 1 and 3 Ratio 65/35	Raw Material 1 and 3 Ratio 50/50	Raw Material 1 and 3 Ratio 80/20		
Sample Type	Field Mixed	Field Mixed	Field Mixed	Field Mixed		
Mass Retained 19.0mm Sieve (%)	0	0	0	0		
Curing Details	**28 Days Normal Curing (23 Deg. C)**	**28 Days Curing Room**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**		
Condition After Curing	Moist	Moist	Moist	Moist		
Method of Addition	Laboratory Mix	Laboratory Mix	Laboratory Mix	Laboratory Mix		
Elapsed Time for Binder (Hrs:Mins)	0:05	0:05	0:05	-1:0-5		
Additive Source	Client Supplied	Client Supplied	Client Supplied	Client Supplied		
Additive Type	60:40 Slag Lime	60:40 Slag Lime	60:40 Slag Lime	60:40 Slag Lime		
ATIC Registration Number	ATIC-140, ATIC-059	ATIC-140, ATIC-059	ATIC-140, ATIC059	ATIC-140, ATIC-059		
Additive Content (%)	5%	5%	5%	7%		
Target Moisture Content (%)	14.0	14.1	14.1	14.1		
Moisture Content (%)	13.5	13.9	14.5	13.9		
Capped 1	No	No	No	No		
Capped 2	No	No	No	No		
Capped 3	No	No	No	No		
Alternate Compaction Method	Standard	Standard	Standard	Standard		
Alternate Compaction Layers	3	3	3	3		
Target Dry Density (t/m^3)	1.96	1.96	1.96	1.96		
Dry Density 1 (t/m^3)	1.96	1.96	1.94	1.96		
Dry Density 2 (t/m^3)	1.96	1.95	1.94	1.95		
Dry Density 3 (t/m^3)	1.97	**	1.95	1.96		
Laboratory Density Ratio (%)	100	100	99	100		
Laboratory Moisture Ratio (%)	96	99	103	99		
UCS Cylinder 1 (MPa)	3.2	2.1	1.0	3.3		
UCS Cylinder 2 (MPa)	3.5	2.2	1.0	2.9		
UCS Cylinder 3 (MPa)	3.3	2.0	1.1	3.1		
UCS Average (MPa)	**3.3**	**2.1**	**1.0**	**3.1**		
Remarks	**	**	**	**		

Material Test Report

Report Number:	**BTK 20018-10**
Issue Number:	1
Date Issued:	17/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	767
Date Sampled:	20/07/2020
Dates Tested:	11/08/2020 - 10/09/2020
Site Selection:	Selected by Client
Lot Number:	Laboratory Testing Phase B

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Manager

NATA Accredited Laboratory Number: 2851

Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-767E	20-767F				
Date Sampled	20/07/2020	20/07/2020				
Date Tested	10/09/2020	10/09/2020				
Sample Location	Pavement Type 5	Pavement Type 6				
Sample Depth	7% Blend	7% Blend				
Material	Research Blends	Research Blends				
Lot Number	Raw Material 1 and 3 Ratio 65/35	Raw Material 1 and 3 Ratio 50/50				
Sample Type	Field Mixed	Field Mixed				
Mass Retained 19.0mm Sieve (%)	0	0				
Curing Details	**28 Days Normal Curing (23 Deg. C)**	**28 Days Curing Room**				
Condition After Curing	Moist	Moist				
Method of Addition	Laboratory Mic	Laboratory Mix				
Elapsed Time for Binder (Hrs:Mins)	0:05	0:05				
Additive Source	Client Supplied	Client Supplied				
Additive Type	60:40 Slag Lime	60:40 Slag Lime				
ATIC Registration Number	ATIC-140, ATIC-059	ATIC-140, ATIC-059				
Additive Content (%)	7%	7%				
Target Moisture Content (%)	14.1	14.1				
Moisture Content (%)	14.2	14.4				
Capped 1	No	No				
Capped 2	No	No				
Capped 3	No	No				
Alternate Compaction Method	Standard	Standard				
Alternate Compaction Layers	3	3				
Target Dry Density (t/m^3)	1.96	1.96				
Dry Density 1 (t/m^3)	1.95	1.95				
Dry Density 2 (t/m^3)	1.95	1.94				
Dry Density 3 (t/m^3)	1.95	1.93				
Laboratory Density Ratio (%)	100	99				
Laboratory Moisture Ratio (%)	101	102				
UCS Cylinder 1 (MPa)	2.5	1.2				
UCS Cylinder 2 (MPa)	3.0	1.8				
UCS Cylinder 3 (MPa)	2.7	1.5				
UCS Average (MPa)	**2.7**	**1.5**				
Remarks	**	**				

Material Test Report

Report Number:	**BTK 20018-11**
Issue Number:	1
Date Issued:	17/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	768
Sample Number:	20-768B
Date Sampled:	20/07/2020
Dates Tested:	11/08/2020 - 01/09/2020
Sample Location:	**Pavement Type 8, Depth: 5% Blend**
Lot No:	**Raw Material 1 and 4 Ratio 65/35**
Material:	Research Blends

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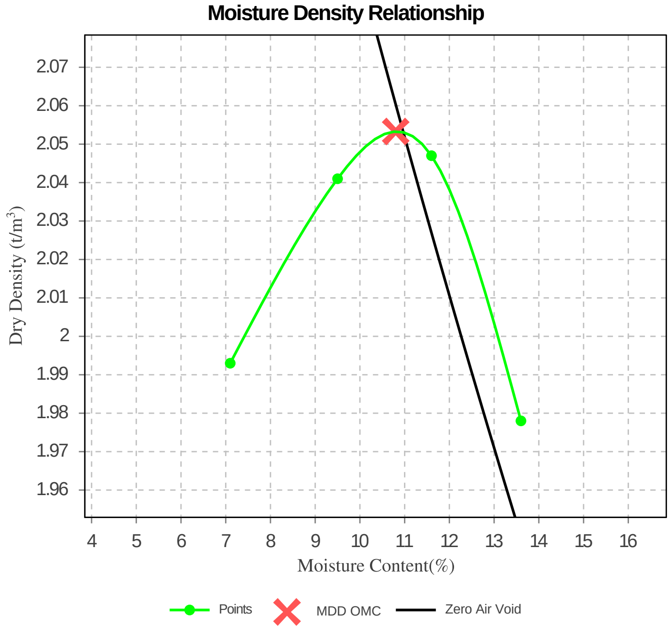
Approved Signatory: James Dick
Manager

NATA Accredited Laboratory Number: 2851

Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	39.0		
Plastic Limit (%)	33.4		
Plasticity Index (%)	**5.6**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	2.6		

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	2.05
Optimum Moisture Content (%)	11.0
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	0.2



Material Test Report

Report Number: **BTK 20018-11**
Issue Number: 1
Date Issued: 17/09/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 768
Date Sampled: 20/07/2020
Dates Tested: 11/08/2020 - 10/09/2020
Site Selection: Selected by Client
Lot Number: Laboratory Testing Phase 3B

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Approved Signatory: James Dick
Manager
NATA Accredited Laboratory Number: 2851

Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-768A	20-768B	20-768C	20-768D		
Date Sampled	20/07/2020	20/07/2020	20/07/2020	20/07/2020		
Date Tested	10/09/2020	10/09/2020	10/09/2020	10/09/2020		
Sample Location	Pavement Type 7	Pavement Type 8	Pavement Type 9	Pavement Type 7		
Sample Depth	5% Blend	5% Blend	5% Blend	7% Blend		
Material	Research Blends	Research Blends	Research Blends	Research Blends		
Lot Number	Raw Material 1 and 4 Ratio 80/20	Raw Material 1 and 4 Ratio 65/35	Raw Material 1 and 4 Ratio 50/50	Raw Material 1 and 4 Ratio 80/20		
Sample Type	Field Mixed	Field Mixed	Field Mixed	Field Mixed		
Mass Retained 19.0mm Sieve (%)	0	0	0	0		
Curing Details	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**		
Condition After Curing	Moist	Moist	Moist	Moist		
Method of Addition	Laboratory Mix	Laboratory Mix	Laboratory Mix	Laboratory Mix		
Elapsed Time for Binder (Hrs:Mins)	0:05	0:05	0:05	0:05		
Additive Source	Client Supplied	Client Supplied	Client Supplied	Client Supplied		
Additive Type	60:40 Slag Lime	60:40 Slag Lime	60:40 Slag Lime	60:40 Slag Lime		
ATIC Registration Number	ATIC-140, ATIC-059	ATIC140, ATIC-059	ATIC-140, ATIC-059	ATIC-140, ATIC-059		
Additive Content (%)	5%	5%	5%	7%		
Target Moisture Content (%)	11.0	10.8	10.8	10.8		
Moisture Content (%)	10.7	10.5	10.9	10.5		
Capped 1	No	No	No	No		
Capped 2	No	No	No	No		
Capped 3	No	No	No	No		
Alternate Compaction Method	Standard	Standard	Standard	Standard		
Alternate Compaction Layers	3	3	3	3		
Target Dry Density (t/m^3)	2.05	2.05	2.05	2.05		
Dry Density 1 (t/m^3)	2.06	2.05	2.04	2.07		
Dry Density 2 (t/m^3)	2.04	2.06	2.05	2.06		
Dry Density 3 (t/m^3)	2.05	2.06	2.05	2.06		
Laboratory Density Ratio (%)	100	100	100	100		
Laboratory Moisture Ratio (%)	97	97	101	97		
UCS Cylinder 1 (MPa)	2.0	1.8	1.2	2.0		
UCS Cylinder 2 (MPa)	2.0	1.8	1.4	2.5		
UCS Cylinder 3 (MPa)	2.1	1.7	1.3	2.4		
UCS Average (MPa)	**2.0**	**1.8**	**1.3**	**2.3**		
Remarks	**	**	**	**		

Material Test Report

Report Number: **BTK 20018-11**
Issue Number: 1
Date Issued: 17/09/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 768
Date Sampled: 20/07/2020
Dates Tested: 11/08/2020 - 10/09/2020
Site Selection: Selected by Client
Lot Number: Laboratory Testing Phase 3B

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Approved Signatory: James Dick
Manager
NATA Accredited Laboratory Number: 2851

Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-768E	20-768F				
Date Sampled	20/07/2020	20/07/2020				
Date Tested	10/09/2020	10/09/2020				
Sample Location	Pavement Type 8	Pavent Type 9				
Sample Depth	7% Blend	7% Blend				
Material	Research Blends	Research Blends				
Lot Number	Raw Material 1 and 4 Ratio 65/35	Raw Material 1 and 4 Ratio 50/50				
Sample Type	Field Mixed	Field Mixed				
Mass Retained 19.0mm Sieve (%)	0	0				
Curing Details	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**				
Condition After Curing	Moist	Moist				
Method of Addition	Laboratory Mix	Laboratory Mix				
Elapsed Time for Binder (Hrs:Mins)	0:05	0:05				
Additive Source	Client Supplied	Client Supplied				
Additive Type	60:40 Slag Lime	60:40 Slag Lime				
ATIC Registration Number	ATIC-140, ATIC-059	ATIC-140, ATIC-059				
Additive Content (%)	7%	7%				
Target Moisture Content (%)	10.8	10.8				
Moisture Content (%)	10.8	10.6				
Capped 1	No	No				
Capped 2	No	No				
Capped 3	No	No				
Alternate Compaction Method	Standard	Standard				
Alternate Compaction Layers	3	**				
Target Dry Density (t/m^3)	2.05	2.05				
Dry Density 1 (t/m^3)	2.03	2.02				
Dry Density 2 (t/m^3)	2.04	2.03				
Dry Density 3 (t/m^3)	2.04	2.03				
Laboratory Density Ratio (%)	99	99				
Laboratory Moisture Ratio (%)	100	98				
UCS Cylinder 1 (MPa)	2.3	2.2				
UCS Cylinder 2 (MPa)	2.3	2.2				
UCS Cylinder 3 (MPa)	2.2	2.1				
UCS Average (MPa)	**2.3**	**2.2**				
Remarks	**	**				

Appendix F:

Laboratory Test Reports, Testing Phase 4 – Lime Ameliorated Cement/Flyash General Blends

Material Test Report

Report Number:	**BTK 20018-13**
Issue Number:	2 - *This version supersedes all previous issues*
Reissue Reason:	*Typing Correction*
Date Issued:	23/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	776
Sample Number:	20-776B
Date Sampled:	20/07/2020
Dates Tested:	17/08/2020 - 04/09/2020
Sample Location:	**Pavement Type 2, Depth: 2% Blend**
Lot No:	**Raw Material 1 and 2 65/35**
Material:	Research Blends

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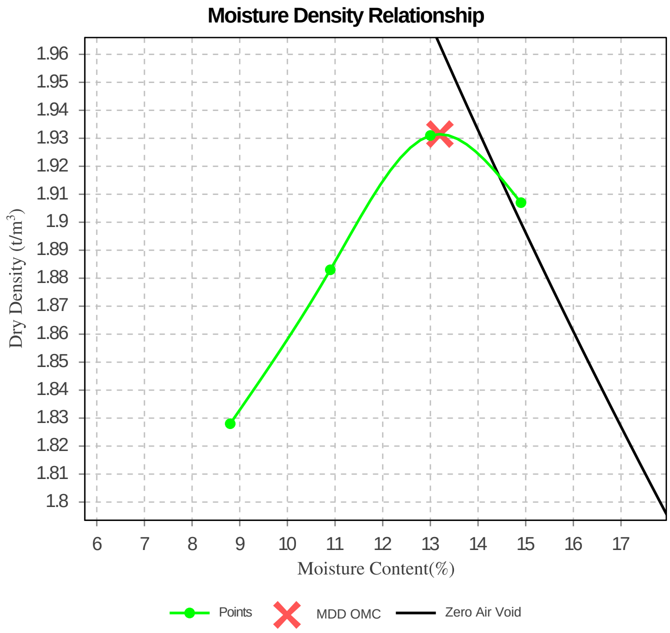
Approved Signatory: Daniel French
Senior Technical Officer

NATA Accredited Laboratory Number: 2851

Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	50.0		
Plastic Limit (%)	40.8		
Plasticity Index (%)	**9.2**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	8.0		

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	1.93
Optimum Moisture Content (%)	13.0
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	0.3



Material Test Report

Report Number:	**BTK 20018-13**
Issue Number:	2 - *This version supersedes all previous issues*
Reissue Reason:	*Typing Correction*
Date Issued:	23/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	776
Sample Number:	20-776E
Date Sampled:	20/07/2020
Dates Tested:	17/08/2020 - 04/09/2020
Sample Location:	**Pavement Type 5, Depth: 2% Blend**
Lot No:	**Raw Material 1 and 3 65/35**
Material:	Research Blends

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Border-Tek Pty Ltd
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NATA WORLD RECOGNISED ACCREDITATION

Accredited for compliance with ISO/IEC 17025 - Testing

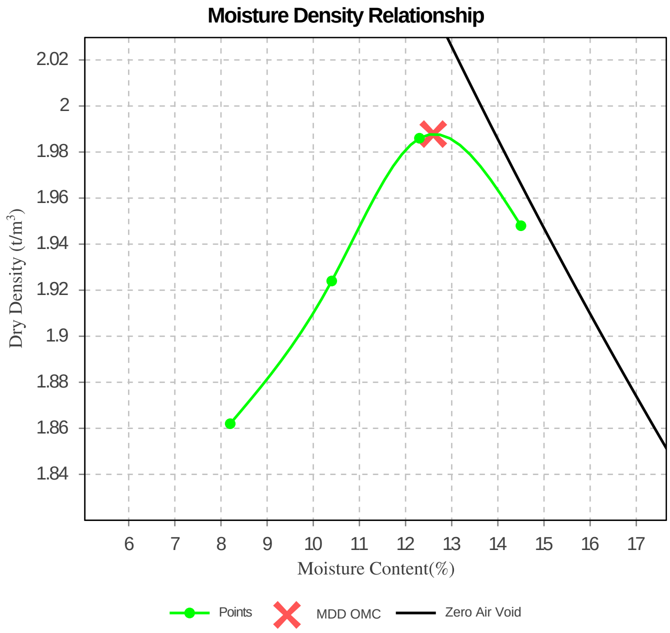
Approved Signatory: Daniel French
Senior Technical Officer

NATA Accredited Laboratory Number: 2851

Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	57.2		
Plastic Limit (%)	53.0		
Plasticity Index (%)	**4.2**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	6.0		

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	1.99
Optimum Moisture Content (%)	12.5
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	0.3



Material Test Report

Report Number:	**BTK 20018-13**
Issue Number:	2 - *This version supersedes all previous issues*
Reissue Reason:	*Typing Correction*
Date Issued:	23/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	776
Sample Number:	20-776H
Date Sampled:	20/07/2020
Dates Tested:	17/08/2020 - 18/09/2020
Sample Location:	**Pavement Type 8, Depth: 2% Blend**
Lot No:	**Raw Material 1 and 4 65/35**
Material:	Research Blends

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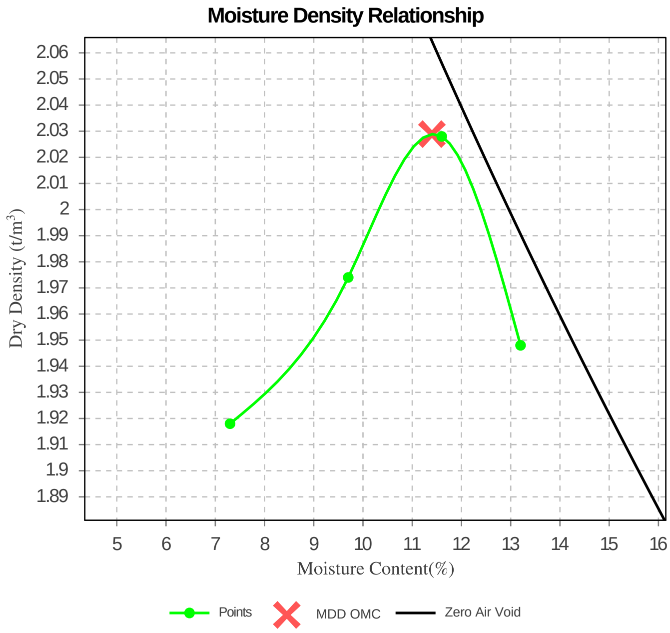
Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	38.6		
Plastic Limit (%)	34.2		
Plasticity Index (%)	**4.4**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	5.0		

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	2.03
Optimum Moisture Content (%)	11.5
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	0.3



Material Test Report

Report Number: **BTK 20018-13**
Issue Number: 2 - *This version supersedes all previous issues*
Reissue Reason: *Typing Correction*
Date Issued: 23/09/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 776
Date Sampled: 20/07/2020
Dates Tested: 17/08/2020 - 18/09/2020
Site Selection: Selected by Client

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NATA WORLD RECOGNISED ACCREDITATION

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Approved Signatory: Daniel French
Senior Technical Officer

NATA Accredited Laboratory Number: 2851

Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-776A	20-776B	20-776C	20-776D		
Date Sampled	20/07/2020	20/07/2020	20/07/2020	20/07/2020		
Date Tested	18/09/2020	18/08/2020	18/09/2020	18/09/2020		
Sample Location	Pavement Type 1	Pavement Type 2	Pavement Type 3	Pavement Type 4		
Sample Depth	2% Blend	2% Blend	2% Blend	2% Blend		
Material	Research Blends	Research Blends	Research Blends	Research Blends		
Lot Number	Raw Material 1 and 2 80/20	Raw Material 1 and 2 65/35	Raw Material 1and 2 50/50	Raw Material 1 and 3 80/20		
Sample Type	Laboratory Mixed	Laboratory Mixed	Laboratory Mixed	Laboratory Mixed		
Mass Retained 19.0mm Sieve (%)	0	0	0	0		
Curing Details	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**		
Condition After Curing	Moist	Moist	Moist	Moist		
Method of Addition	Laboratory Mix	Laboratory Mix	Laboratory Mix	Laboratory Mix		
Elapsed Time for Binder (Hrs:Mins)	0:42	0:42	0:41	0:41		
Additive Source	Client Supplied	Client Supplied	Client Supplied	Client Supplied		
Additive Type	70:30 Cement Flyash	70:30 Cement Flyash	70:30 Cement Flyash	70:30 Cement Flyash		
ATIC Registration Number	ATI -059, ATIC-118, ATIC-069	ATIC-059, ATIC118 ,ATIC-069	ATIC-059, ATIC-118, ATIC069	ATIC-059, ATIC-118, ATIC-069		
Additive Content (%)	3% Lime / 2% Additive	3% Lime / 2% Additive	3% Lime, 2% Additive	3.% Lime / 2% Additive		
Target Moisture Content (%)	13.0	13.2	13.2	13.2		
Moisture Content (%)	12.4	13.2	13.5	12.8		
Capped 1	No	No	No	No		
Capped 2	No	No	No	No		
Capped 3	No	No	No	No		
Alternate Compaction Method	Standard	Standard	Standard	Standard		
Alternate Compaction Layers	3	3	3	3		
Target Dry Density (t/m^3)	1.93	1.93	1.93	1.93		
Dry Density 1 (t/m^3)	1.93	1.90	1.91	1.98		
Dry Density 2 (t/m^3)	1.93	1.91	1.91	1.98		
Dry Density 3 (t/m^3)	1.92	1.92	1.90	1.98		
Laboratory Density Ratio (%)	100	99	99	102		
Laboratory Moisture Ratio (%)	95	100	102	97		
UCS Cylinder 1 (MPa)	1.5	0.9	0.6	1.5		
UCS Cylinder 2 (MPa)	1.7	1.5	0.5	1.7		
UCS Cylinder 3 (MPa)	1.6	1.6	0.5	1.5		
UCS Average (MPa)	**1.6**	**1.3**	**0.5**	**1.6**		
Remarks	**	**	**	**		

Material Test Report

Report Number:	**BTK 20018-13**
Issue Number:	2 - *This version supersedes all previous issues*
Reissue Reason:	*Typing Correction*
Date Issued:	23/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	776
Date Sampled:	20/07/2020
Dates Tested:	17/08/2020 - 18/09/2020
Site Selection:	Selected by Client

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NATA WORLD RECOGNISED ACCREDITATION

Approved Signatory: Daniel French
Senior Technical Officer

NATA Accredited Laboratory Number: 2851

Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-776E	20-776F	20-776G	20-776H		
Date Sampled	20/07/2020	20/07/2020	20/07/2020	20/07/2020		
Date Tested	18/09/2020	18/09/2020	18/09/2020	18/09/2020		
Sample Location	Pavement Type 5	Pavement Type 6	Pavement Type 7	Pavement Type 8		
Sample Depth	2% Blend	2% Blend	2% Blend	2% Blend		
Material	Research Blends	Research Blends	Research Blends	Research Blends		
Lot Number	Raw Material 1 and 3 65/35	Raw Material 1 and 3 50/50	Raw Material 1and 4 80/20	Raw Material 1 and 4 65/35		
Sample Type	Laboratory Mixed	Field Mixed	Laboratory Mixed	Laboratory Mixed		
Mass Retained 19.0mm Sieve (%)	0	0	0	0		
Curing Details	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**		
Condition After Curing	Moist	Moist	Moist	Moist		
Method of Addition	Laboratory Mix	Laboratory Mix	Laboratory Mix	Laboratory Mix		
Elapsed Time for Binder (Hrs:Mins)	0:41	0:41	0:45	0:43		
Additive Source	Client Supplied	Client Supplied	Client Supplied	Client Supplied		
Additive Type	70:30 Cement Flyash	70:30 Cement Flyash	70:30 Cement Flyash	70:30 Cement Flyash		
ATIC Registration Number	ATIC -059, ATIC-118, ATIC-069	ATIC- 059, ATIC-118, ATIC-069	ATIC-059,ATIC-118,ATIC-069	ATIC-059, ATIC-118, ATIC-069		
Additive Content (%)	3% Lime / 2% Additive	3% Lime / 2% Additive	3% Lime / 2% Additive	3% Lime / 2% Additive		
Target Moisture Content (%)	12.6	12.6	12.6	11.4		
Moisture Content (%)	12.4	12.8	10.7	11.2		
Capped 1	No	No	No	No		
Capped 2	No	No	No	No		
Capped 3	No	No	No	No		
Alternate Compaction Method	Standard	Standard	Standard	Standard		
Alternate Compaction Layers	3	3	3	3		
Target Dry Density (t/m^3)	1.99	1.99	1.99	2.03		
Dry Density 1 (t/m^3)	1.98	1.98	2.03	2.03		
Dry Density 2 (t/m^3)	1.98	1.98	2.04	2.02		
Dry Density 3 (t/m^3)	1.99	1.99	2.04	2.03		
Laboratory Density Ratio (%)	100	100	102	100		
Laboratory Moisture Ratio (%)	98	102	85	98		
UCS Cylinder 1 (MPa)	1.6	1.1	0.9	0.9		
UCS Cylinder 2 (MPa)	1.6	1.4	1.3	0.8		
UCS Cylinder 3 (MPa)	1.7	1.1	1.3	0.9		
UCS Average (MPa)	**1.6**	**1.2**	**1.2**	**0.9**		
Remarks	**	**	**	**		

Material Test Report

Report Number: **BTK 20018-13**
Issue Number: 2 - *This version supersedes all previous issues*
Reissue Reason: *Typing Correction*
Date Issued: 23/09/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 776
Date Sampled: 20/07/2020
Dates Tested: 17/08/2020 - 18/09/2020
Site Selection: Selected by Client

Border-Tek Pty Ltd
Tweed Heads Laboratory
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Approved Signatory: Daniel French
Senior Technical Officer
NATA Accredited Laboratory Number: 2851

Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-776I					
Date Sampled	20/07/2020					
Date Tested	18/09/2020					
Sample Location	Pavement Type 9					
Sample Depth	2% Blend					
Material	Research Blends					
Lot Number	Raw Material 1 and 4 50/50					
Sample Type	Laboratory Mixed					
Mass Retained 19.0mm Sieve (%)	0					
Curing Details	**28 Days Normal Curing (23 Deg. C)**					
Condition After Curing	Moist					
Method of Addition	laboratory Mix					
Elapsed Time for Binder (Hrs:Mins)	0:45					
Additive Source	Client Supplied					
Additive Type	70:30 Cement Flyash					
ATIC Registration Number	000 / 118 / 069					
Additive Content (%)	3% Lime / 2% Additive					
Target Moisture Content (%)	11.4					
Moisture Content (%)	11.5					
Capped 1	No					
Capped 2	No					
Capped 3	No					
Alternate Compaction Method	Standard					
Alternate Compaction Layers	3					
Target Dry Density (t/m^3)	2.03					
Dry Density 1 (t/m^3)	2.03					
Dry Density 2 (t/m^3)	2.03					
Dry Density 3 (t/m^3)	2.03					
Laboratory Density Ratio (%)	100					
Laboratory Moisture Ratio (%)	101					
UCS Cylinder 1 (MPa)	1.2					
UCS Cylinder 2 (MPa)	1.2					
UCS Cylinder 3 (MPa)	1.2					
UCS Average (MPa)	**1.2**					
Remarks	**					

Material Test Report

Report Number:	**BTK 20018-14**
Issue Number:	1
Date Issued:	23/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	777
Sample Number:	20-777B
Date Sampled:	20/07/2020
Dates Tested:	17/08/2020 - 18/09/2020
Sample Location:	**Pavement Type 2, Depth: 3% Blend**
Lot No:	**Raw Material 1 and 2 65/35**
Material:	Research Blends

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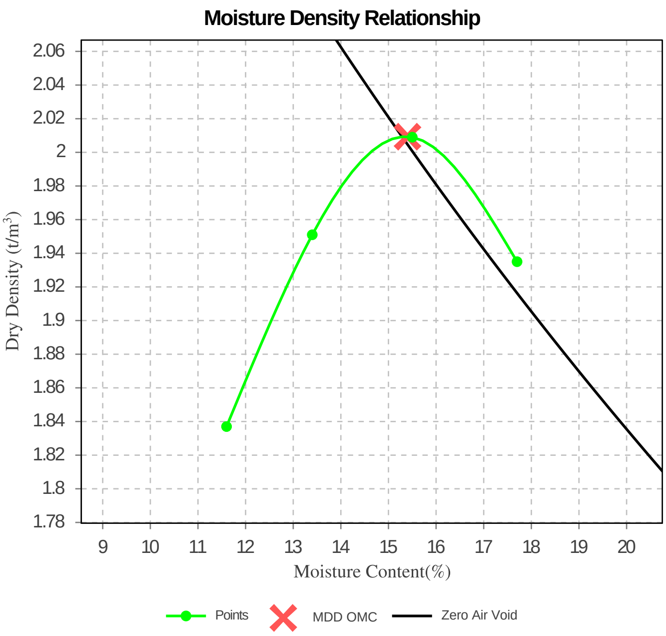
Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	48.6		
Plastic Limit (%)	41.6		
Plasticity Index (%)	**7.0**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	7.6		

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	2.01
Optimum Moisture Content (%)	15.5
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	0.3



Material Test Report

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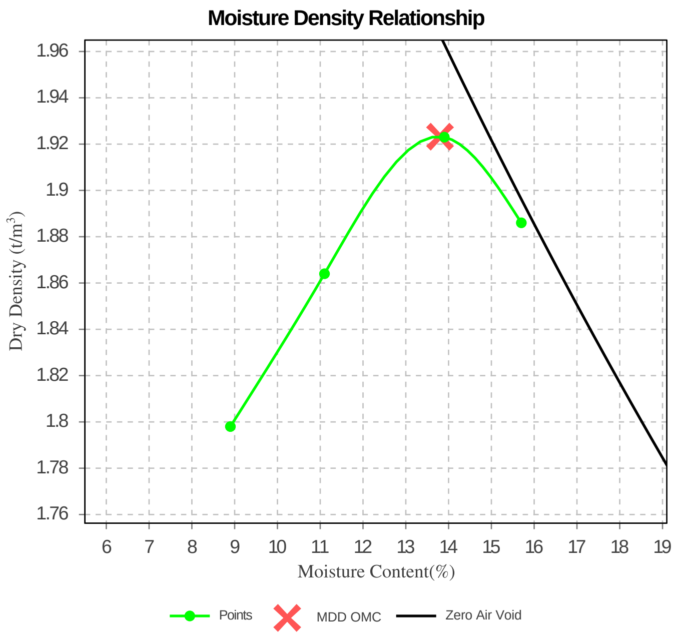
Report Number:	**BTK 20018-14**
Issue Number:	1
Date Issued:	23/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	777
Sample Number:	20-777E
Date Sampled:	20/07/2020
Dates Tested:	17/08/2020 - 01/09/2020
Sample Location:	**Pavement Type 5, Depth: 3% Blend**
Lot No:	**Raw Material 1 and 3 65/35**
Material:	Research Blends

Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	55.2		
Plastic Limit (%)	52.6		
Plasticity Index (%)	**2.6**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	4.0		

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	1.92
Optimum Moisture Content (%)	14.0
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	0.3



Material Test Report

Report Number:	**BTK 20018-14**
Issue Number:	1
Date Issued:	23/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	777
Sample Number:	20-777H
Date Sampled:	20/07/2020
Dates Tested:	17/08/2020 - 28/08/2020
Sample Location:	**Pavement Type 8, Depth: 3% Blend**
Lot No:	**Raw Material 1 and 4 65/35**
Material:	Research Blends

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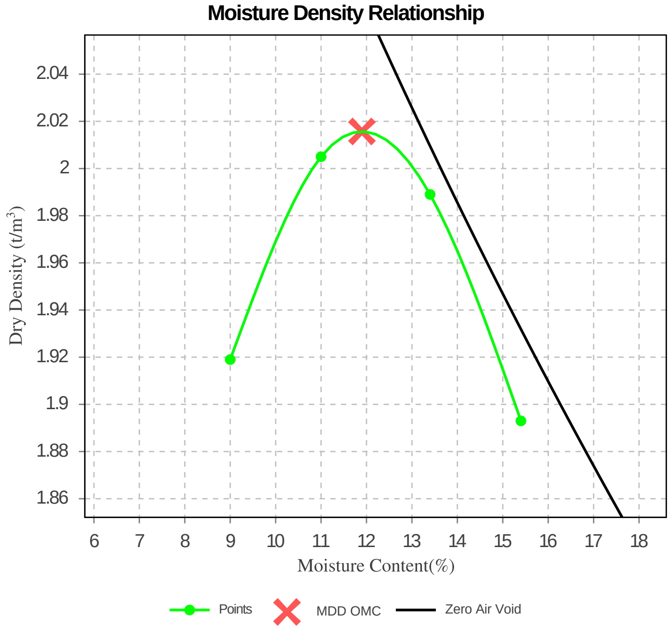
Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	40.2		
Plastic Limit (%)	35.8		
Plasticity Index (%)	**4.4**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	3.4		

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	2.02
Optimum Moisture Content (%)	12.0
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	0.3



Material Test Report

Report Number:	**BTK 20018-14**
Issue Number:	1
Date Issued:	23/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	777
Date Sampled:	20/07/2020
Dates Tested:	17/08/2020 - 22/09/2020
Site Selection:	Selected by Client

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NATA Accredited Laboratory Number: 2851

Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-777A	20-777B	20-777C	20-777D		
Date Sampled	20/07/2020	20/07/2020	20/07/2020	20/07/2020		
Date Tested	22/09/2020	22/09/2020	22/09/2020	22/09/2020		
Sample Location	Pavement Type 1	Pavement Type 2	Pavement Type 3	Pavement Type 4		
Sample Depth	3% Blend	3% Blend	3% Blend	3% Blend		
Material	Research Blends	Research Blends	Research Blends	Research Blends		
Lot Number	Raw Material 1 and 2 80/20	Raw Material 1 and 2 65/35	Raw Material 1 and 2 50/50	Raw Blend 1 and 3 Ratio 80/20		
Sample Type	Laboratory Mixed	Laboratory Mixed	Laboratory Mixed	Field Mixed		
Mass Retained 19.0mm Sieve (%)	0	0	0	0		
Curing Details	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**		
Condition After Curing	Moist	Moist	Moist	Moist		
Method of Addition	Laboratory Mix	Laboratory Mix	Laboratory Mix	Laboratory Mix		
Elapsed Time for Binder (Hrs:Mins)	0:40	0:42	0:45	0:42		
Additive Source	Client Supplied	Client Supplied	Client Supplied	Client Supplied		
Additive Type	70:30 Cement Flyash	70:30 Cement Flyash	70:30 Cement Flyash	70:30 Cement Flyash		
ATIC Registration Number	ATIC-059, ATIC-118, ATIC-069	ATIC-059, ATIC-118, ATIC-069	ATIC-059, ATIC-118, ATIC-069	ATIC-059, ATIC-118, ATIC-069		
Additive Content (%)	3% Lime / 3% Additive	3% Lime / 3% Additive	3% Lime / 3% Additive	3% Lime / 3% Additive		
Target Moisture Content (%)	15.5	15.4	15.4	14.0		
Moisture Content (%)	14.2	15.4	15.8	13.3		
Capped 1	No	No	No	No		
Capped 2	No	No	No	No		
Capped 3	No	No	No	No		
Alternate Compaction Method	Standard	Standard	Standard	Standard		
Alternate Compaction Layers	3	3	3	3		
Target Dry Density (t/m^3)	2.00	2.01	2.01	1.92		
Dry Density 1 (t/m^3)	2.04	2.01	2.02	1.93		
Dry Density 2 (t/m^3)	2.02	2.00	2.01	1.94		
Dry Density 3 (t/m^3)	2.03	2.01	2.00	1.93		
Laboratory Density Ratio (%)	102	100	100	101		
Laboratory Moisture Ratio (%)	92	100	103	95		
UCS Cylinder 1 (MPa)	2.0	1.1	1.2	2.4		
UCS Cylinder 2 (MPa)	1.8	1.0	1.2	2.6		
UCS Cylinder 3 (MPa)	1.9	1.0	1.1	2.3		
UCS Average (MPa)	**1.9**	**1.0**	**1.2**	**2.4**		
Remarks	**	**	**	**		

Material Test Report

Report Number: **BTK 20018-14**
Issue Number: 1
Date Issued: 23/09/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 777
Date Sampled: 20/07/2020
Dates Tested: 17/08/2020 - 22/09/2020
Site Selection: Selected by Client

BORDER-TEK PTY LTD
GEOTECHNICAL TESTING SERVICES
Border-Tek Pty Ltd
Tweed Heads Laboratory
Unit 11/21 Enterprise Avenue Tweed Heads South NSW 2486
Phone: (07) 55246199
Email: info@bordertek.com.au

NATA WORLD RECOGNISED ACCREDITATION

Accredited for compliance with ISO/IEC 17025 - Testing

Approved Signatory: Daniel French
Senior Technical Officer

NATA Accredited Laboratory Number: 2851

Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-777E	20-777F	20-777G	20-777H		
Date Sampled	20/07/2020	20/07/2020	20/07/2020	20/07/2020		
Date Tested	22/09/2020	22/09/2020	22/09/2020	22/09/2020		
Sample Location	Pavement Type 5	Pavement Type 6	Pavement Type 7	Pavement Type 8		
Sample Depth	3% Blend	3% Blend	3% Blend	3% Blend		
Material	Research Blends	Research Blends	Research Blends	Research Blends		
Lot Number	Raw Material 1 and 3 65/35	Raw Material 1 and 3 50/50	Raw Material 1 and 4 80/20	Raw Material 1 and 4 65/35		
Sample Type	Laboratory Mixed	Laboratory Mixed	Laboratory Mixed	Laboratory Mixed		
Mass Retained 19.0mm Sieve (%)	0	0	0	0		
Curing Details	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**		
Condition After Curing	Moist	Moist	Moist	Moist		
Method of Addition	Laboratory Mix	Laboratory Mix	Laboratory Mix	Laboratory Mix		
Elapsed Time for Binder (Hrs:Mins)	0:45	0:43	0:52	0:45		
Additive Source	Client Supplied	Client Supplied	Client Supplied	Client Supplied		
Additive Type	70:30 Cement Flyash	70:30 Cement Flyash	70:30 Cement Flyash	70:30 Cement Flyash		
ATIC Registration Number	ATIC-059, ATIC-118, ATIC-069	ATIC-059, ATIC-118, ATIC-069	ATIC-059, ATIC-118, ATIC-069	ATIC-059, ATIC-118, ATIC-069		
Additive Content (%)	3% Lime / 3% Additive	3% Lime / 3% Additive	3% Lime / 3% Additive	3% Lime / 3% Additive		
Target Moisture Content (%)	13.8	13.8	12.0	11.9		
Moisture Content (%)	13.9	14.2	11.2	11.7		
Capped 1	No	No	No	No		
Capped 2	No	No	No	No		
Capped 3	No	No	No	No		
Alternate Compaction Method	Standard	Standard	Standard	Standard		
Alternate Compaction Layers	3	3	3	3		
Target Dry Density (t/m^3)	1.92	1.92	2.02	2.02		
Dry Density 1 (t/m^3)	1.94	1.94	2.05	2.04		
Dry Density 2 (t/m^3)	1.93	1.93	2.04	2.04		
Dry Density 3 (t/m^3)	1.93	1.92	2.04	2.05		
Laboratory Density Ratio (%)	100	100	101	101		
Laboratory Moisture Ratio (%)	101	103	93	98		
UCS Cylinder 1 (MPa)	2.0	2.0	1.4	1.2		
UCS Cylinder 2 (MPa)	1.8	2.0	1.5	1.3		
UCS Cylinder 3 (MPa)	1.9	2.0	1.4	1.3		
UCS Average (MPa)	**1.9**	**2.0**	**1.4**	**1.3**		
Remarks	**	**	**	**		

Material Test Report

Report Number: **BTK 20018-14**
Issue Number: 1
Date Issued: 23/09/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 777
Date Sampled: 20/07/2020
Dates Tested: 17/08/2020 - 22/09/2020
Site Selection: Selected by Client

Border-Tek Pty Ltd
Tweed Heads Laboratory
Unit 11/21 Enterprise Avenue Tweed Heads South NSW 2486
Phone: (07) 55246199
Email: info@bordertek.com.au

Accredited for compliance with ISO/IEC 17025 - Testing

Approved Signatory: Daniel French
Senior Technical Officer

NATA Accredited Laboratory Number: 2851

Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-777I					
Date Sampled	20/07/2020					
Date Tested	22/09/2020					
Sample Location	Pavement Type 9					
Sample Depth	3% Blend					
Material	Research Blends					
Lot Number	Raw Material 1 and 4 50/50					
Sample Type	Laboratory Mixed					
Mass Retained 19.0mm Sieve (%)	0					
Curing Details	**28 Days Normal Curing (23 Deg. C)**					
Condition After Curing	Moist					
Method of Addition	Laboratory Mix					
Elapsed Time for Binder (Hrs:Mins)	0:40					
Additive Source	Client Supplied					
Additive Type	70:30 Cement Flyash					
ATIC Registration Number	ATIC-059, ATIC-118, ATIC-069					
Additive Content (%)	3% Lime / 3% Additive					
Target Moisture Content (%)	11.9					
Moisture Content (%)	12.3					
Capped 1	No					
Capped 2	No					
Capped 3	No					
Alternate Compaction Method	Standard					
Alternate Compaction Layers	3					
Target Dry Density (t/m^3)	2.02					
Dry Density 1 (t/m^3)	2.03					
Dry Density 2 (t/m^3)	2.03					
Dry Density 3 (t/m^3)	2.04					
Laboratory Density Ratio (%)	101					
Laboratory Moisture Ratio (%)	103					
UCS Cylinder 1 (MPa)	1.6					
UCS Cylinder 2 (MPa)	1.5					
UCS Cylinder 3 (MPa)	1.7					
UCS Average (MPa)	**1.6**					
Remarks	**					

Material Test Report

Report Number: **BTK 20018-15**
Issue Number: 2 - *This version supersedes all previous issues*
Reissue Reason: *Add Shrinkage*
Date Issued: 23/09/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 778
Sample Number: 20-778B
Date Sampled: 20/07/2020
Dates Tested: 17/08/2020 - 01/09/2020
Sample Location: **Pavent Type 2, Depth: 4% Blend**
Lot No: **Raw Material 1 and 2 65/35**
Material: Research Blends

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Accredited for compliance with ISO/IEC 17025 - Testing

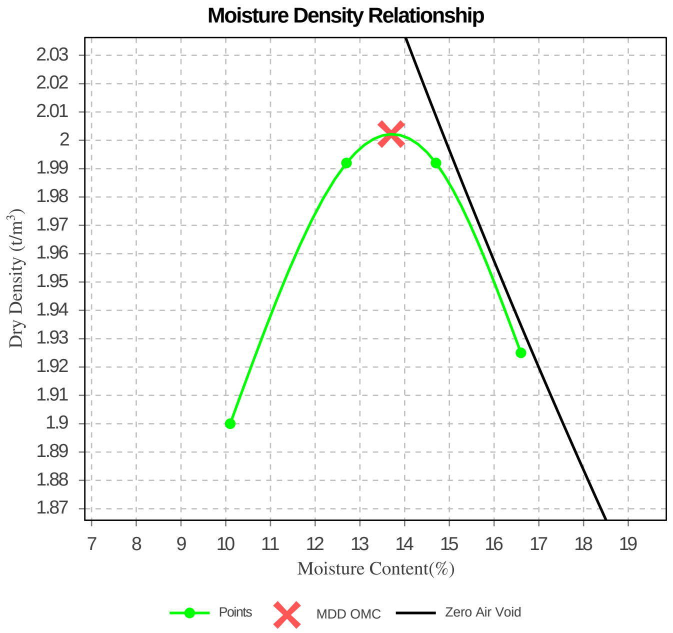
Approved Signatory: Daniel French
Senior Technical Officer

NATA Accredited Laboratory Number: 2851

Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	47.6		
Plastic Limit (%)	42.6		
Plasticity Index (%)	**5.0**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	4.0		

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	2.00
Optimum Moisture Content (%)	13.5
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	0.3



Material Test Report

Report Number:	**BTK 20018-15**
Issue Number:	2 - *This version supersedes all previous issues*
Reissue Reason:	*Add Shrinkage*
Date Issued:	23/09/2020
Client:	Stabilised Pavements of Australia Pty Ltd 67 Boundary Street, Beenleigh Qld 4207
Contact:	Scott Young
Project Number:	BTK 20018
Project Name:	Basegrade Stabilisation Research
Work Request:	778
Sample Number:	20-778E
Date Sampled:	20/07/2020
Dates Tested:	17/08/2020 - 01/09/2020
Sample Location:	**Pavement Type 5, Depth: 4% Blend**
Lot No:	**Raw Material 1 and 3 65/35**
Material:	Research Blends

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Tweed Heads Laboratory
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Accredited for compliance with ISO/IEC 17025 - Testing

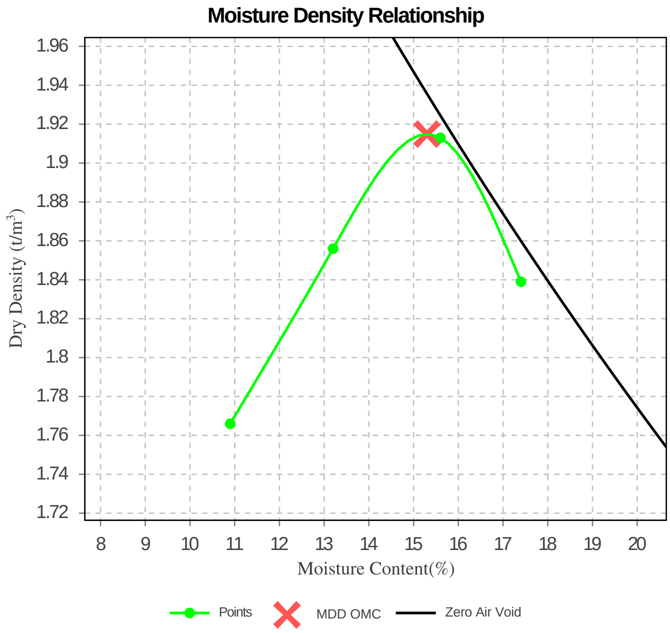
Approved Signatory: Daniel French
Senior Technical Officer

NATA Accredited Laboratory Number: 2851

Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	39.4		
Plastic Limit (%)	34.0		
Plasticity Index (%)	**5.4**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	4.0		

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	1.91
Optimum Moisture Content (%)	15.5
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	0.3



Material Test Report

Border-Tek Pty Ltd
Tweed Heads Laboratory
Unit 11/21 Enterprise Avenue Tweed Heads South NSW 2486
Phone: (07) 55246199
Email: info@bordertek.com.au

Accredited for compliance with ISO/IEC 17025 - Testing

Approved Signatory: Daniel French
Senior Technical Officer

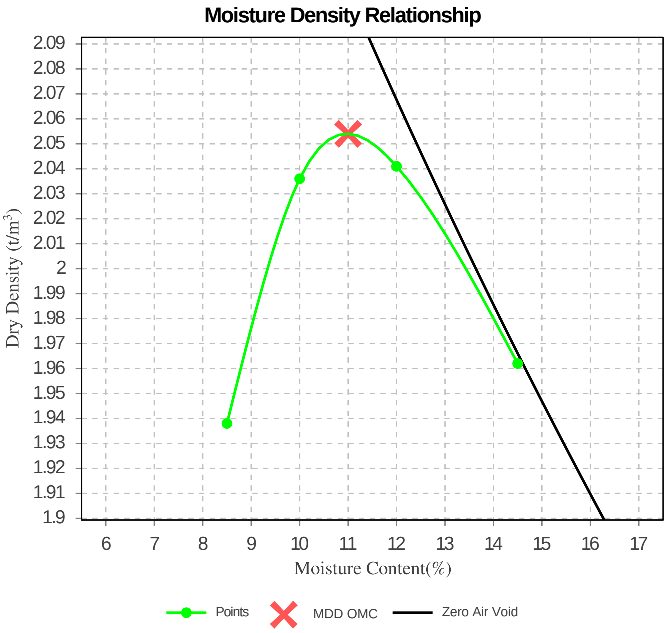
NATA Accredited Laboratory Number: 2851

Report Number: **BTK 20018-15**
Issue Number: 2 - *This version supersedes all previous issues*
Reissue Reason: *Add Shrinkage*
Date Issued: 23/09/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 778
Sample Number: 20-778H
Date Sampled: 20/07/2020
Dates Tested: 17/08/2020 - 01/09/2020
Sample Location: **Pavement Type 8, Depth: 4% Blend**
Lot No: **Raw Material 1 and 4 65/35**
Material: Research Blends

Atterberg Limit (Q104D & Q105 & AS 1289.2.1.1)		Min	Max
Liquid Limit (%)	41.0		
Plastic Limit (%)	36.0		
Plasticity Index (%)	**5.0**		

Linear Shrinkage (Q106)		Min	Max
Shrinkage Drying Type	Oven Dried		
Linear Shrinkage (%)	3.4		

Dry Density - Moisture Relationship (Q142A & AS 1289.2.1.1)	
Mould Type	1 LITRE MOULD A
Compaction	Standard
Maximum Dry Density (t/m^3)	2.05
Optimum Moisture Content (%)	11.0
Oversize Sieve (mm)	19
Oversize Material Wet (%)	0
Oversize Material Dry (%)	0
Dry Oversize density (t/m^3)	
Method used to Determine Plasticity	Visual/Tactile
Curing Hours	0.3



Material Test Report

Report Number: **BTK 20018-15**
Issue Number: 2 - *This version supersedes all previous issues*
Reissue Reason: *Add Shrinkage*
Date Issued: 23/09/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 778
Date Sampled: 20/07/2020
Dates Tested: 17/08/2020 - 22/09/2020
Site Selection: Selected by Client

Border-Tek Pty Ltd
Tweed Heads Laboratory
Unit 11/21 Enterprise Avenue Tweed Heads South NSW 2486
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Accredited for compliance with ISO/IEC 17025 - Testing

Approved Signatory: Daniel French
Senior Technical Officer
NATA Accredited Laboratory Number: 2851

Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-778A	20-778B	20-778C	20-778D		
Date Sampled	20/07/2020	20/07/2020	20/07/2020	20/07/2020		
Date Tested	22/09/2020	22/09/2020	22/09/2020	22/09/2020		
Sample Location	Pavement Type 1	Pavent Type 2	Pavement Type 3	Pavement Type 4		
Sample Depth	4% Blend	4% Blend	4% Blend	4% Blend		
Material	Research Blends	Research Blends	Research Blends	Research Blends		
Lot Number	Raw Material 1 and 2 80/20	Raw Material 1 and 2 65/35	Raw Material 1 and 2 50/50	Raw Material 1 and 3 80/20		
Sample Type	Laboratory Mixed	Laboratory Mixed	Laboratory Mixed	Laboratory Mixed		
Mass Retained 19.0mm Sieve (%)	0	0	0	0		
Curing Details	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**		
Condition After Curing	Moist	Moist	Moist	Moist		
Method of Addition	Laboratory Mix	Laboratory Mix	Standard	Laboratory Mix		
Elapsed Time for Binder (Hrs:Mins)	0:42	0:45	0:45	0:50		
Additive Source	Client Supplied	Client Supplied	Client Supplied	Client Supplied		
Additive Type	70:30 Cement Flyash	70:30 Cement Flyash	70:30 Cement Flyash	70:30 Cement Flyash		
ATIC Registration Number	ATIC-059, ATIC-118, ATIC-069	ATIC-059, ATIC-118, ATIC-069	ATIC-059, ATIC-118, ATIC-069	ATIC059, ATIC-118, ATIC-069		
Additive Content (%)	3% Lime / 4% Additive	3% Lime / 4% Additive	3% Lime / 4% Additive	3% Lime / 4% Additive		
Target Moisture Content (%)	15.5	15.5	15.5	15.0		
Moisture Content (%)	14.4	15.3	14.5	14.2		
Capped 1	No	No	No	No		
Capped 2	No	No	No	No		
Capped 3	No	No	No	No		
Alternate Compaction Method	Standard	Standard	Standard	Standard		
Alternate Compaction Layers	3	3	3	3		
Target Dry Density (t/m^3)	2.00	2.00	2.00	1.91		
Dry Density 1 (t/m^3)	2.03	2.00	2.02	1.92		
Dry Density 2 (t/m^3)	2.01	2.00	2.01	1.91		
Dry Density 3 (t/m^3)	2.03	2.00	2.01	1.91		
Laboratory Density Ratio (%)	101	100	101	100		
Laboratory Moisture Ratio (%)	93	99	94	95		
UCS Cylinder 1 (MPa)	3.2	2.3	0.9	2.8		
UCS Cylinder 2 (MPa)	3.2	1.9	0.8	2.8		
UCS Cylinder 3 (MPa)	3.0	2.0	0.8	2.7		
UCS Average (MPa)	**3.1**	**2.1**	**0.8**	**2.8**		
Remarks	**	**	**	**		

Material Test Report

Report Number: **BTK 20018-15**
Issue Number: 2 - *This version supersedes all previous issues*
Reissue Reason: *Add Shrinkage*
Date Issued: 23/09/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 778
Date Sampled: 20/07/2020
Dates Tested: 17/08/2020 - 22/09/2020
Site Selection: Selected by Client

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Approved Signatory: Daniel French
Senior Technical Officer
NATA Accredited Laboratory Number: 2851

Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-778E	20-778F	20-778G	20-778H		
Date Sampled	20/07/2020	20/07/2020	20/07/2020	20/07/2020		
Date Tested	22/09/2020	22/09/2020	22/09/2020	22/09/2020		
Sample Location	Pavement Type 5	Pavement Type 6	Pavement Type 7	Pavement Type 8		
Sample Depth	4% Blend	4% Blend	4% Blend	4% Blend		
Material	Research Blends	Research Blends	Research Blends	Research Blends		
Lot Number	Raw Material 1 and 3 65/35	Raw Material 1 and 3 50/50	Raw Material 1 and 4 80/20	Raw Material 1 and 4 65/35		
Sample Type	Laboratory Mixed	Laboratory Mixed	Laboratory Mixed	Laboratory Mixed		
Mass Retained 19.0mm Sieve (%)	0	0	0	0		
Curing Details	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**	**28 Days Normal Curing (23 Deg. C)**		
Condition After Curing	Moist	Moist	Moist	Moist		
Method of Addition	Laboratory Mix	Laboratory Mix	Laboratory Mix	Standard		
Elapsed Time for Binder (Hrs:Mins)	0:43	0:53	0:45	0:45		
Additive Source	Client Supplied	Client Supplied	Client Supplied	Client Supplied		
Additive Type	70:30 Cement Flyash	70:30 Cement Flyash	70:30 Cement Flyash	70:30 Cement Flyash		
ATIC Registration Number	ATIC-059, ATIC-118, ATIC-069	ATIC-059, ATIC-118, ATIC-069	ATIC-059, ATIC-118, ATIC-069	ATIC-059, ATIC-118, ATIC-069		
Additive Content (%)	3% Lime / 4% Additive	3% Lime / 4% Additive	3% Lime / 4% Additive	3% Lime / 4% Additive		
Target Moisture Content (%)	15.3	15.3	11.0	11.0		
Moisture Content (%)	15.2	16.1	10.8	10.8		
Capped 1	No	No	No	No		
Capped 2	No	No	No	No		
Capped 3	No	No	No	No		
Alternate Compaction Method	Standard	Standard	Standard	Standard		
Alternate Compaction Layers	3	3	3	3		
Target Dry Density (t/m^3)	1.91	1.91	1.91	2.05		
Dry Density 1 (t/m^3)	1.91	1.90	1.99	2.06		
Dry Density 2 (t/m^3)	1.90	1.89	1.97	2.06		
Dry Density 3 (t/m^3)	1.90	1.89	1.98	2.04		
Laboratory Density Ratio (%)	99	99	97	100		
Laboratory Moisture Ratio (%)	99	105	98	98		
UCS Cylinder 1 (MPa)	2.8	2.7	1.8	1.9		
UCS Cylinder 2 (MPa)	2.4	2.6	1.6	1.6		
UCS Cylinder 3 (MPa)	2.7	2.4	1.7	1.8		
UCS Average (MPa)	**2.6**	**2.6**	**1.7**	**1.8**		
Remarks	**	**	**	**		

Material Test Report

Report Number: **BTK 20018-15**
Issue Number: 2 - *This version supersedes all previous issues*
Reissue Reason: *Add Shrinkage*
Date Issued: 23/09/2020
Client: Stabilised Pavements of Australia Pty Ltd
67 Boundary Street, Beenleigh Qld 4207
Contact: Scott Young
Project Number: BTK 20018
Project Name: Basegrade Stabilisation Research
Work Request: 778
Date Sampled: 20/07/2020
Dates Tested: 17/08/2020 - 22/09/2020
Site Selection: Selected by Client

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Phone: (07) 55246199
Email: info@bordertek.com.au

Accredited for compliance with ISO/IEC 17025 - Testing

Approved Signatory: Daniel French
Senior Technical Officer

NATA Accredited Laboratory Number: 2851

Unconfined Compressive Strength (Q115 & AS 1289.2.1.1)					Min	Max
Sample Number	20-778I					
Date Sampled	20/07/2020					
Date Tested	22/09/2020					
Sample Location	Pavement Type 9					
Sample Depth	4% Blend					
Material	Research Blends					
Lot Number	Raw Material 1 and 4 50/50					
Sample Type	Laboratory Mixed					
Mass Retained 19.0mm Sieve (%)	0					
Curing Details	**28 Days Normal Curing (23 Deg. C)**					
Condition After Curing	Moist					
Method of Addition	Laboratory Mix					
Elapsed Time for Binder (Hrs:Mins)	0:43					
Additive Source	Client Supplied					
Additive Type	70:30 Cement Flyash					
ATIC Registration Number	ATIC-059, ATIC-118, ATIC-069					
Additive Content (%)	3% Lime / 4% Additive					
Target Moisture Content (%)	11.0					
Moisture Content (%)	11.2					
Capped 1	No					
Capped 2	No					
Capped 3	No					
Alternate Compaction Method	Standard					
Alternate Compaction Layers	3					
Target Dry Density (t/m^3)	2.05					
Dry Density 1 (t/m^3)	2.05					
Dry Density 2 (t/m^3)	2.04					
Dry Density 3 (t/m^3)	2.05					
Laboratory Density Ratio (%)	100					
Laboratory Moisture Ratio (%)	102					
UCS Cylinder 1 (MPa)	1.5					
UCS Cylinder 2 (MPa)	1.6					
UCS Cylinder 3 (MPa)	1.6					
UCS Average (MPa)	**1.6**					
Remarks	**					

Appendix G:

Laboratory Test Reports, Port Macquarie Hastings Council Case Study

Coffs Harbour Laboratory

Coffey Services Australia Pty Ltd
ABN 55 139 460 521
22 Ray McCarthy Drive
Coffs Harbour NSW 2450

Phone: +61 2 6691 7300
Fax: +61 2 6651 5194

coffey
A TETRA TECH COMPANY

Report No: SAGG:COFH19S-00138
Issue No: 1

Aggregate/Soil Test Report

Client: Stabilised Pavements of Australia Pty Ltd
234 Wisemans Ferry Road
Somersby NSW 2250

Principal:
Project No.: INFOCOFH00417AC
Project Name: Stabilised Pavements - General Testing
Lot No.: Lot 2 **TRN:** Lot 2

NATA
WORLD RECOGNISED ACCREDITATION

Accredited for compliance with ISO/IEC 17025 - Testing.

The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards.

Approved Signatory: Scott Archibald
(Geotechnician)
NATA Accredited Laboratory Number:431
Date of Issue: 7/02/2019

Sample Details

Sample ID: COFH19S-00138
Date Sampled: 31/01/2019
Date Submitted: 31/01/2019
Date Tested: 7/02/2019
Project Location: Wauchope NSW
Sample Location: Fairmont Drive, 42.76, 7.46, Left

Sampling Method: AS1289.1.2.1 Clause 6.4 (a)
Material: Stabilised Base
Source: In situ
Specification: No Specification

General Test Results

RMS T116

Binder: 60:40 Slag:Lime Blend
Compaction Method: Standard
Condition of Curing: accelerated
Mass Retained on 19.0mm (%): 5

Binder Source: Client supplied
Specimen Curing Period: 7
Average UCS (MPa): 1.5
Remarks: -

Specimen Test Results

No	Moisture at Compacting (%)	Dry Density (t/m³)	UCS (MPa)	Condition After Curing	Percentage of Binder (%)	Binder Curing Period
1	13.5	1.93	1.40	Moist	5.0	4h:50m
2	13.5	1.93	1.65	Moist	5.0	5h:5m

Comments

Coffs Harbour Laboratory

Coffey Services Australia Pty Ltd
ABN 55 139 460 521
22 Ray McCarthy Drive
Coffs Harbour NSW 2450

Phone: +61 2 6691 7300
Fax: +61 2 6651 5194

coffey
A TETRA TECH COMPANY

Report No: SAGG:COFH19S-00140
Issue No: 1

Aggregate/Soil Test Report

Client: Stabilised Pavements of Australia Pty Ltd
234 Wisemans Ferry Road
Somersby NSW 2250

Principal:
Project No.: INFOCOFH00417AC
Project Name: Stabilised Pavements - General Testing
Lot No.: Lot 2 **TRN:** Lot 2

Accredited for compliance with ISO/IEC 17025 - Testing.

The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards.

NATA
WORLD RECOGNISED ACCREDITATION

Approved Signatory: Scott Archibald
(Geotechnician)
NATA Accredited Laboratory Number:431
Date of Issue: 7/02/2019

Sample Details

Sample ID:	COFH19S-00140	**Sampling Method:**	AS1289.1.2.1 Clause 6.4 (a)
Date Sampled:	31/01/2019	**Material:**	Stabilised Base
Date Submitted:	31/01/2019	**Source:**	In situ
Date Tested:	7/02/2019	**Specification:**	No Specification
Project Location:	Wauchope NSW		
Sample Location:	Cogo Close, 15.87, 8.30, Left		

General Test Results

RMS T116

Binder:	60:40 Slag:Lime Blend	**Binder Source:**	Client supplied
Compaction Method:	Standard	**Specimen Curing Period:**	7
Condition of Curing:	Accelerated	**Average UCS (MPa):**	1.3
Mass Retained on 19.0mm (%):	5	**Remarks:**	-

Specimen Test Results

No	Moisture at Compacting (%)	Dry Density (t/m³)	UCS (MPa)	Condition After Curing	Percentage of Binder (%)	Binder Curing Period
1	14.0	1.91	1.30	Moist	5.0	3h:55m
2	14.0	1.91	1.40	Moist	5.0	4h:10m

Comments

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Aggregate/Soil Test Report

Report No: SAGG:COFH19S-00281
Issue No: 1

Client: Stabilised Pavements of Australia Pty Ltd
234 Wisemans Ferry Road
Somersby NSW 2250

Principal:
Project No.: INFOCOFH00417AC
Project Name: Stabilised Pavements - General Testing
Lot No.: Lot 2 **TRN:** Lot 2

Accredited for compliance with ISO/IEC 17025 - Testing.

The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards.

NATA
WORLD RECOGNISED ACCREDITATION

Approved Signatory: Scott Archibald (Geotechnician)
NATA Accredited Laboratory Number:431
Date of Issue: 25/02/2019

Sample Details

Sample ID:	COFH19S-00281	**Sampling Method:**	AS1289.1.2.1 Clause 6.4 (a)
Date Sampled:	15/02/2019	**Material:**	Stabilised Base
Date Submitted:	15/02/2019	**Source:**	In situ
Date Tested:	22/02/2019	**Specification:**	No Specification
Project Location:	Wauchope NSW		
Sample Location:	Colonial Circuit, Ch 48.05 m, 0.2 m, Left, Base		

General Test Results

RMS T116

Binder:	60:40 Slag:Lime Blend	**Binder Source:**	Client supplied
Compaction Method:	Standard	**Specimen Curing Period:**	7
Condition of Curing:	accelerated	**Average UCS (MPa):**	2.6
Mass Retained on 19.0mm (%):	4	**Remarks:**	-

Specimen Test Results

No	Moisture at Compacting (%)	Dry Density (t/m³)	UCS (MPa)	Condition After Curing	Percentage of Binder (%)	Binder Curing Period
1	12.5	1.97	2.45	Moist	5.0	4h:10m
2	12.5	1.98	2.75	Moist	5.0	4h:25m

Comments

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Report No: SAGG:COFH19S-00283
Issue No: 1

Aggregate/Soil Test Report

Client: Stabilised Pavements of Australia Pty Ltd
234 Wisemans Ferry Road
Somersby NSW 2250

Principal:
Project No.: INFOCOFH00417AC
Project Name: Stabilised Pavements - General Testing
Lot No.: Lot 2 **TRN:** Lot 2

Accredited for compliance with ISO/IEC 17025 - Testing.

The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards.

NATA
WORLD RECOGNISED ACCREDITATION

Approved Signatory: Scott Archibald
(Geotechnician)
NATA Accredited Laboratory Number:431
Date of Issue: 25/02/2019

Sample Details

Sample ID:	COFH19S-00283	**Sampling Method:**	AS1289.1.2.1 Clause 6.4 (a)
Date Sampled:	15/02/2019	**Material:**	Stabilised Base
Date Submitted:	15/02/2019	**Source:**	In situ
Date Tested:	22/02/2019	**Specification:**	No Specification
Project Location:	Wauchope NSW		
Sample Location:	Colonial Circuit, Ch 115.25 m, 9.88 m, Left, Base		

General Test Results

RMS T116

Binder:	60:40 Slag:Lime Blend	**Binder Source:**	Client supplied
Compaction Method:	Standard	**Specimen Curing Period:**	7
Condition of Curing:	Accelerated	**Average UCS (MPa):**	2.6
Mass Retained on 19.0mm (%):	4	**Remarks:**	-

Specimen Test Results

No	Moisture at Compacting (%)	Dry Density (t/m³)	UCS (MPa)	Condition After Curing	Percentage of Binder (%)	Binder Curing Period
1	11.5	1.99	2.40	Moist	5.0	3h:55m
2	11.5	1.99	2.80	Moist	5.0	4h:10m

Comments

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Aggregate/Soil Test Report

Report No: SAGG:COFH18S-01632
Issue No: 1

Client: Stabilised Pavements of Australia Pty Ltd
234 Wisemans Ferry Road
Somersby NSW 2250

Principal:
Project No.: INFOCOFH00417AC
Project Name: Stabilised Pavements - General Testing
Lot No.: Lot 2 **TRN:** Lot 2

NATA
WORLD RECOGNISED ACCREDITATION

Accredited for compliance with ISO/IEC 17025 - Testing.

The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards.

Approved Signatory: Paul Smith
(Laboratory Manager)
NATA Accredited Laboratory Number:431
Date of Issue: 27/06/2018

Sample Details

Sample ID:	COFH18S-01632	**Sampling Method:**	T100 - AS1289.1.2.1 Clause 6.4 (b)
Date Sampled:	18/06/2018	**Material:**	Stabilised Base
Date Submitted:		**Source:**	In situ
Date Tested:	19/06/2018	**Specification:**	
Project Location:	Sarah's Crecsent, Kings Creek		
Sample Location:	Sarah's Crescent, Ch 65 m, 1.4 m, Left		

General Test Results

RMS T116

Binder:	60:40 Slag:Lime Blend	**Binder Source:**	Client supplied
Compaction Method:	Standard	**Specimen Curing Period:**	7
Condition of Curing:	Accelerated	**Average UCS (MPa):**	0.6
Mass Retained on 19.0mm (%):	2	**Remarks:**	-

Specimen Test Results

No	Moisture at Compacting (%)	Dry Density (t/m³)	UCS (MPa)	Condition After Curing	Percentage of Binder (%)	Binder Curing Period
1	11.5	1.99	0.70	Moist	2.0	5h:15m
2		2.21	0.55	Moist	2.0	4h:50m

Comments

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Report No: SAGG:COFH18S-01634
Issue No: 1

Aggregate/Soil Test Report

Client: Stabilised Pavements of Australia Pty Ltd
234 Wisemans Ferry Road
Somersby NSW 2250

Principal:
Project No.: INFOCOFH00417AC
Project Name: Stabilised Pavements - General Testing
Lot No.: Lot 2 **TRN:** Lot 2

Accredited for compliance with ISO/IEC 17025 - Testing.

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NATA
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Approved Signatory: Paul Smith
(Laboratory Manager)
NATA Accredited Laboratory Number:431
Date of Issue: 27/06/2018

Sample Details

Sample ID: COFH18S-01634
Sampling Method: T100 - AS1289.1.2.1 Clause 6.4 (b)
Date Sampled: 18/06/2018
Material: Stabilised Base
Date Submitted:
Source: In situ
Date Tested: 19/06/2018
Specification:
Project Location: Sarah's Crecsent, Kings Creek
Sample Location: Sarah's Crescent, Ch 193 m, 5.5 m, Left

General Test Results

RMS T116

Binder: 60:40 Slag:Lime Blend
Binder Source: Client supplied
Compaction Method: Standard
Specimen Curing Period: 7
Condition of Curing: Accelerated
Average UCS (MPa): 3.4
Mass Retained on 19.0mm (%): 1
Remarks: -

Specimen Test Results

No	Moisture at Compacting (%)	Dry Density (t/m³)	UCS (MPa)	Condition After Curing	Percentage of Binder (%)	Binder Curing Period
1	11.0	2.00	3.30	Moist	2.0	29h:40m
2		2.22	3.45	Moist	2.0	29h:35m

Comments

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Report No: SAGG:COFH18S-01657
Issue No: 1

Aggregate/Soil Test Report

Client: Stabilised Pavements of Australia Pty Ltd
234 Wisemans Ferry Road
Somersby NSW 2250

Principal:
Project No.: INFOCOFH00417AC
Project Name: Stabilised Pavements - General Testing
Lot No.: Lot 4 **TRN:** Lot 4

Accredited for compliance with ISO/IEC 17025 - Testing.

The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards.

NATA
WORLD RECOGNISED ACCREDITATION

Approved Signatory: Scott Archibald (Geotechnician)
NATA Accredited Laboratory Number:431
Date of Issue: 28/06/2018

Sample Details

Sample ID:	COFH18S-01657	**Sampling Method:**	T100 - AS1289.1.2.1 Clause 6.4 (a)
Date Sampled:	20/06/2018	**Material:**	Stabilised Base
Date Submitted:	20/06/2018	**Source:**	In situ
Date Tested:	27/06/2018	**Specification:**	No Specification
Project Location:	Kings Creek		
Sample Location:	Sarahs Crescent, Ch 45.15 m, 7.3 m, Left		

General Test Results

RMS T116

Binder:	60:40 Slag:Lime Blend	**Binder Source:**	Client supplied
Compaction Method:	Standard	**Specimen Curing Period:**	7
Condition of Curing:	Accelerated	**Average UCS (MPa):**	0.6
Mass Retained on 19.0mm (%):		**Remarks:**	-

Specimen Test Results

No	Moisture at Compacting (%)	Dry Density (t/m^3)	UCS (MPa)	Condition After Curing	Percentage of Binder (%)	Binder Curing Period
1	11.0		0.55	Moist	2.0	5h:0m
2			0.70	Moist	2.0	4h:45m

Comments

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Report No: SAGG:COFH18S-01659
Issue No: 1

Aggregate/Soil Test Report

Client: Stabilised Pavements of Australia Pty Ltd
234 Wisemans Ferry Road
Somersby NSW 2250

Principal:
Project No.: INFOCOFH00417AC
Project Name: Stabilised Pavements - General Testing
Lot No.: Lot 4 **TRN:** Lot 4

NATA
WORLD RECOGNISED ACCREDITATION

Accredited for compliance with ISO/IEC 17025 - Testing.

The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards.

Approved Signatory: Scott Archibald (Geotechnician)
NATA Accredited Laboratory Number:431
Date of Issue: 28/06/2018

Sample Details

Sample ID:	COFH18S-01659	**Sampling Method:**	T100 - AS1289.1.2.1 Clause 6.4 (a)
Date Sampled:	20/06/2018	**Material:**	Stabilised Base
Date Submitted:	20/06/2018	**Source:**	In situ
Date Tested:	27/06/2018	**Specification:**	No Specification
Project Location:	Kings Creek		
Sample Location:	Sarahs Crescent, Ch 115.15 m, 0.2 m, Left		

General Test Results

RMS T116

Binder:	60:40 Slag:Lime Blend	**Binder Source:**	Client supplied
Compaction Method:	Standard	**Specimen Curing Period:**	8
Condition of Curing:	Accelerated	**Average UCS (MPa):**	1.7
Mass Retained on 19.0mm (%):		**Remarks:**	-

Specimen Test Results

No	Moisture at Compacting (%)	Dry Density (t/m³)	UCS (MPa)	Condition After Curing	Percentage of Binder (%)	Binder Curing Period
1	11.5		1.70	Moist	2.0	5h:30m
2			1.70	Moist	2.0	5h:30m

Comments

Appendix H:

Proposed Mix Design Procedure for Basegrade Stabilisation

General Notes:

- Start on the left hand side and work towards the right hand side;
- At any point in the chart, if the answer to a question is YES, follow the green solid line;
- At any point in the chart, if the answer to a question is NO, follow the red dashed line;

Specific Notes:

1a. Existing granular thickness can include bituminous wearing surface where no level restrictions exist. Additional material refers to a review of the opportunity to raise the level of the existing pavement with another suitable unbound material (eg. a granular overlay).

1b. Engineering judgement is required on a case by case basis to assess the heavy vehicle traffic spectrum for the site against the specific basegrade pavement being considered.

2a. The sieve analysis is for the combined pavement granular and subgrade material, ie. the basegrade mixture, prior to the addition of any stabilising binder/s.

2b. The linear shrinkage and plasticity index values are for the combined pavement granular and subgrade material, ie. the basegrade mixture, prior to the addition of any stabilising binder/s. Both variables do not need to comply together. If either the linear shrinkage or plasticity index variable is found to satisfy the respective assigned limits, progression to the next stage is permitted.

3a/3b. Insitu CBR usually refers to an estimate onsite during an investigation (eg. with a dynamic cone penetrometer, or back calculated from deflection data). This variable is only for the untreated subgrade.

3c/3d. This is the proportion of the subgrade as a percentage of the total basegrade thickness to be stabilised, eg. If the design thickness is 250mm and the existing pavement thickness is 150mm, the subgrade proportion represents 100mm of the total basegrade thickness, or 40%.

4a. For soft subgrades where the insitu CBR<3%, the suggested trial mix design is intended to be a two phase process where phase 1 is an initial lime pre-treatment to a thickness of at least 300mm. Phase 2 occurs after at least 24 hours of amelioration (usually the next shift) to the design thickness which is intended to be at least 50-100mm less than the initial lime pre-treatment thickness. This is to enable the phase 1 treatment to produce a subbase, or buffer between the cement/flyash treatment and the soft subgrade during phase 2. Binder type and application rates for phase 2 are based on optimisation from the research outcomes. Adjustments can be made based on local knowledge and/or experience.

4b/4c. Two binder types and two corresponding application rates are provided to trial. These are based on optimisation from the research outcomes. One or both mix designs can be trialled.

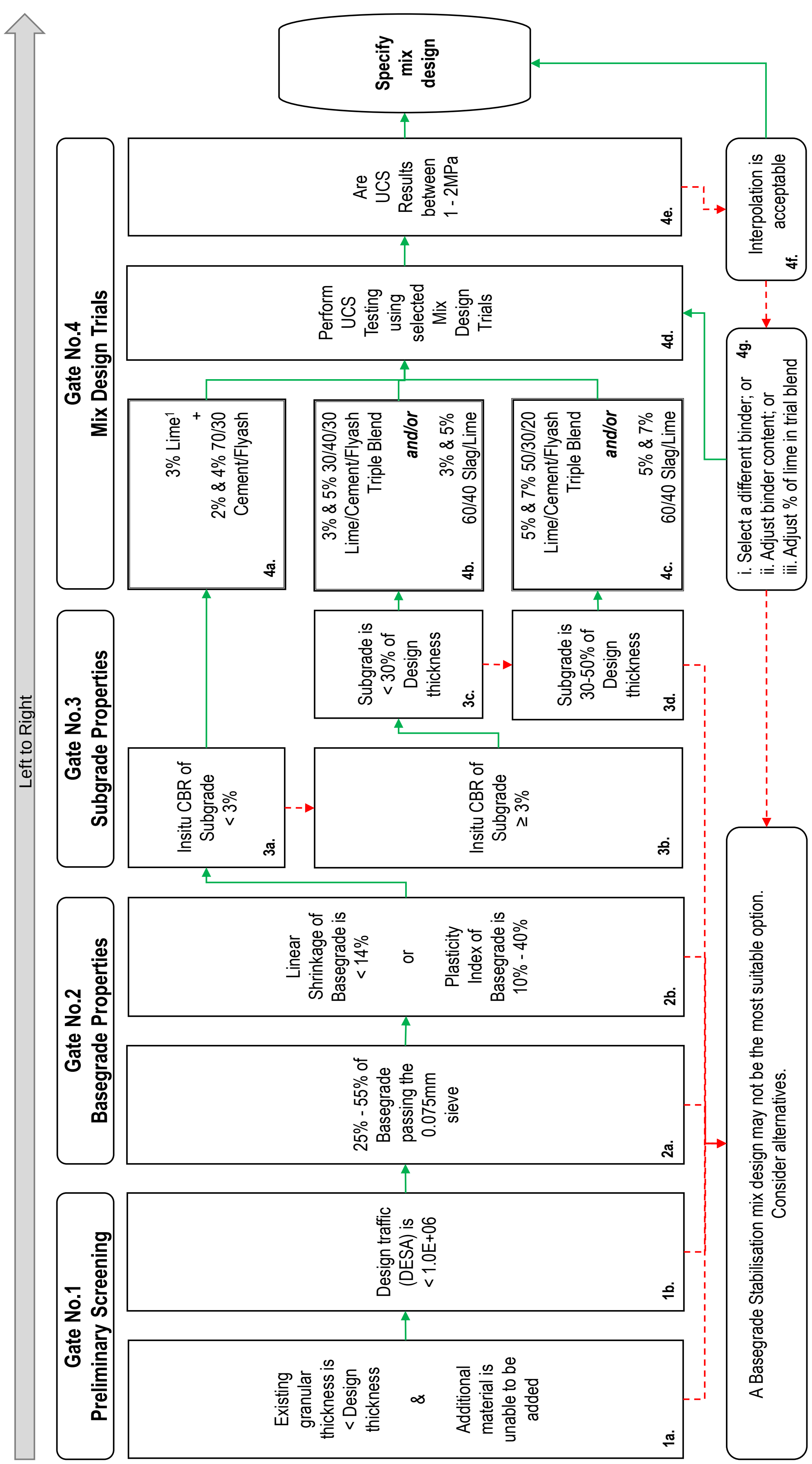
4d. UCS testing is recommended to be undertaken after 28 days of curing at ambient temperature in accordance with local government or state government jurisdiction test methods. Accelerated curing at raised temperatures to obtain results after 7 days may be undertaken in accordance where a test method exists (eg. Transport for NSW Test Method T131).

4e. Evaluation of a series of UCS results should be based on consideration of homogeneous lots, where the coefficient of variation does not exceed 30%. Typically the mean result from a series of UCS test results is evaluated against the target strength range of 1-2MPa. Outliers should be investigated further as they may skew the data set.

4f. Where UCS results are outside the target strength range of 1-2MPa, selection of a mix design application rate is permissible by interpolation from a plot of the results. Interpolation may not be considered suitable where all results are either below or above the target strength range (but not both). However forward or backward forecasting of trend lines with a moderate to strong coefficient of determination (R^2 > 0.5) may reveal adequate results.

4g. For option i. an adjustment to the binder type may produce different results (eg. the cement/flyash component of blends could be exchanged for a slag/cement.
For option ii. Adjustment of the binder application rate (%) may produce different results. A +/- 1% change in binder application rate may alter the UCS by +/- 0.25MPa to 0.5MPa.
For option iii. The lime content within the blends may be adjusted to produce different results (eg. 3% lime in the pre-treatment phase could be increased to 4%, or the 30/40/30 lime/cement/flyash triple blend could be adjusted to 40/40/20.

It is recommended that any adjustments to trial mix designs are done one at a time so that changes in results can be attributed to a single variable.



1. Minimum 24 hours amelioration period recommended prior to addition of 70/30 cement/flyash.