Ash Development Association of Australia

MODIFIED AND STABILISED CONSTRUCTION MATERIALS INCORPORATING COAL COMBUSTION PRODUCTS

Fly Ash Reference Data Sheet NO. 13
2012

1. INTRODUCTION

The use of stabilised materials in road construction and maintenance has gained considerable acceptance as a result of:

- Scarcity of high quality quarry materials
- The ability to successfully recycle pavements insitu gaining economic and environmental benefits
- The development of a wide range of binders
- The development of pavement and materials design protocols

Some work on the use of fly ash in modified and bound road construction materials is available including descriptions of applications.[1] Stabilised materials can be classified in one of three ways:

i. Mechanically stabilised materials where inert materials are added to improve the grading of unbound materials
ii. Modified materials where small amounts of binder are added to unbound materials to improve material characteristics while maintaining the materials' unbound performance characteristics
iii. Bound (stabilised) materials where sufficient binder is added to significantly increase the tensile strength of the material[3]

Coal combustion products (CCPs) cover a range of materials and are used in all of the situations described above. CCPs can be broadly classified as follows:

- Furnace Bottom Ash (FBA)
- Fly Ash (FA) conforming to AS 3582.1 Fine, Medium or Coarse grades,[3] and
- Fly Ash not conforming to AS 3582.1 (often termed Run of Station ash or ROS ash)

CCPs fulfil a key role in binder design as a slow-setting binder, improving binder characteristics and reducing costs.

2. PAVEMENT MATERIALS

Stabilised pavement materials can be classified as:

- Plant mixed stabilised materials
- Insitu stabilised materials
- Sub grade stabilised materials

Further information on the use of these types of materials in a range of pavement types as well as binder types suggested for various applications are provided in Austroads 2012.[2]

3. PAVEMENT DESIGN: THE ROLE OF STABILISATION

Pavement materials include a combination of coarse and fine aggregates with a proportion of smaller clay/silt sized particles. The objective is to ensure a final grading matrix that will allow maximum compaction of the product with the least voids present. This is to achieve a solid layer that is in part impervious to water infiltration. Pavement materials can be used in different layers of the pavement and the requirements of such layers will be determined by applied load and pavement composition selected by the designer.

Typical pavement configurations for pavements incorporating stabilised materials are illustrated in Figure 1.

The design of pavements with stabilised layers is covered in detail in the Austroads Guide for Pavement Structural Design.[2]

For pavements containing mechanically stabilised materials and/or modified materials, the limiting design criterion is the vertical strain at the top of the sub grade. For stabilised and higher binder content materials, the vertical strain at the top of the sub grade is not the only design criterion as the fatigue life of the cemented material must also be considered. The fatigue life of the cemented material is usually the governing criterion.

High performance quarried materials will likely be obtained from the nearest possible source in order to minimise transport costs. Often, however, imported material may not be sufficiently strong to satisfy the pavement design requirements. In such cases, the solution is found in the design of either stronger pavement layers or a reduction in the stress requirement for the layer. One of the most cost effective ways to make the pavement stronger is to modify or stabilise the pavement material. As an alternative, it is possible to reduce the stress requirement by stiffening the foundation. Again, this can be done by either modifying or stabilising the foundation.

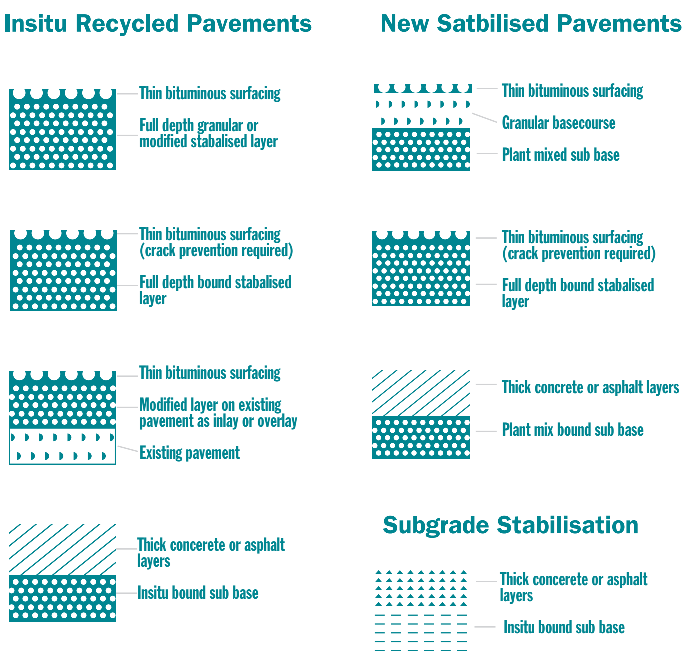

Fig. 1: Typical Pavement Configurations Incorporating Stabilised Materials (Adapted from 2)

4. BINDING PROCESS

By combining the available materials with a small percentage of binder, physical and mechanical properties of the layer can be improved. The binder may act as a glue or it may simply modify the pavement layer properties to allow easier access by construction traffic. In pavement construction where heavy duty performance is required, or where pavement materials (base and sub base) require improvement, these can be either modified and/or stabilised, depending on the needs of the pavement design. The requirement for modification or stabilisation is based on the specified material stiffness.

The material binding process utilises specialised machinery that mixes the binder evenly through the pavement material. Machines such as that shown in Figure 2 are commonly used for pavement stabilisation. Machines used are capable of mixing up to 450 mm depth in pavement.

Fig. 2 Example of a Deep Lift Stabilise[7]

The binding agents used can vary significantly in type and performance. Trialling is considered essential to confirm the likely properties of the pavement materials and stabilising agents. Commonly used stabilising materials include cement, FA, slag and lime. Apart from cement, such materials rely on a pozzolanic reaction for their binding properties. Both FA and slag react with free lime to form cementitious compounds that are forms of calcium silicate hydrates. There are also other products such as polymers which can be used as binders. Austroads Guide to Pavement Technology – Part 4L – Stabilising Binders (2009) provides detailed information on available binder types.

5. MECHANICAL, MODIFIED OR STABILISED BINDING

5.1 SELECTION OF BINDERS

Depending on the nature of the host road base material, a combination of stabilising agents may be used including cement, slag, FA or lime. In some cases a triple blend may be applied to produce a slow setting binder that gains stiffness and strength over a longer time frame. Through testing and trialling, combinations of binder materials are developed and then specified.

This improvement in the strength and stiffness as a result of stabilisation also results in a subsequent reduction in pavement permeability.

In addition, there are a number of construction advantages resulting from increased stiffness with a thinner pavement required and the ability to compact thicker layers following placement. This reduces construction time through a reduction in the number of layers requiring placement and compaction. In design, excessive strength development is to be avoided. High strength gain can result in a loss of pavement flexibility and leads to cracking in response to applied stress. The differences between Granular (Mechanical), Modified and Bound materials are illustrated in Table 1.

5.2 CCPS AND BINDERS

Either FA as defined in AS 3582.1[3] or ROS ash that has properties outside those noted in that standard can be used with lime or cement for the modification of road base materials.

General Purpose (GP) cement on its own can be used as a binder, but requires care with the limited working time to ensure compaction and ride quality are achieved prior to initial setting.

FA and lime have much slower reaction rates and result in a slower strength development and more appropriate material working times. Chapman and Youdale[5] evaluated FBA based pavements in 1982. The residual strength of the material was found to be stronger than that of conventional base course material that was re-compacted up to six days after placement.[5]

5.3 LIME STABILISATION

Lime stabilisation or modification is used in road construction to improve the quality of existing material within the construction project. Lime is an effective additive for plastic soils, improving both workability and strength.[4] Lime stabilisation can be used to:

- Modify marginal material to bring it within specification or for performance requirements
- Increase strength as an alternative to cementitious stabilisation
- Enhance volumetric stability for various layers of select material
- Improve surface stability of unsealed roads

5.4 CEMENTITIOUS STABILISATION

When stabilising with cement, the working time of the resultant material can be critical. The time available to deliver, incorporate and compact a pavement layer needs to be well understood before project commencement. With cement as the only binder, the time for performing placement and compaction processes is limited to approximately two hours from the incorporation of the cement into the moistened pavement material. No rework time is normally provided for. This can create a very demanding schedule with little opportunity for error management on site.

Cement as the only binder is not often used due to these working time restrictions. In addition, higher shrinkage rates can result in an increased cracking tendency. Addition of FA to the binder extends the working life of the stabilised material, allows more time placement in compaction of the material and mitigates risks typically associated with a single cement binder.

Category of stabilisation	Indicative laboratory strength after stabilisation	Common binders adopted	Anticipated performance attributes
Granular (Mechanical)	40% < CBR1 < +100% (sub base and base course)	• Blending other granular materials which are classified as binders	• Improved pavement stiffness • Improved shear strength • Improved resistance to aggregate breakdown
Modified	0.7MPa < UCS2 < 1.03 MPa (base course)	• Addition of small amounts of cementitious binders • Addition of lime • Addition of chemical binder	• Improved pavement stiffness • Improved shear strength • Reduced moisture sensitivity • At low binder contents can be subject to erosion where cracking is present
Bound	UCS2 > 1.0 MPa (base course)	• Addition of greater quantities of cementitious binder • Addition of a combination of cementitious and bituminous binders	• Increased pavement stiffness to provide tensile resistance • Some binders induce transverse shrinkage cracking • At low binder contents can be subject to erosion where cracking is present
Sub grade	CBR1 > 5% (sub grade and formation)	• Addition of lime • Addition of chemical binder	• Improved sub grade stiffness • Improved shear strength • Reduced heave and shrinkage

Table 1 Types of Stabilisation[2]

Notes:

1. Four day soaked CBR
2. Values determined from test specimens stabilised with GP cement and prepared using standard compactive effort, normal curing for 28 days and 4 hour soak conditioning
3. It is vital that this value is not exceeded or the pavement design will be invalid and premature failure as a result of cracking is likely

6. APPLICATION OF CCPS IN PAVEMENTS

6.1 FLY ASH

FA is light to mid-grey in colour and similar but often paler in appearance to cement. Particle sizes range typically between less than 1 micrometre (μm) to 200 μm and are irregular to spherical in shape depending on the material source and formation. FA tends to be pozzolanic in nature, reacting with calcium hydroxide in the presence of water to form cementitious compounds.[6,7,8]

6.2 FURNACE BOTTOM ASH

FBA is formed when ash adheres as hot particles to the furnace walls at coal fired power stations, agglomerates and then falls to the base of the furnace where it is collected and transferred to the storage facility. FBA can comprise 10-20% of the CCPs produced from a power station and ranges in grain size from fine sand to coarse particles up to 5 mm in size. It has a chemical composition similar to FA but may contain greater proportions of carbon (Loss on Ignition or LOI) and is relatively inert because it is coarser and more highly fused than FA.

The coarse particles make an excellent free draining material and are very beneficial as a drainage layer. FBA has a role in granular stabilisation for improving the grading of crusher run materials. Given the coarser nature of FBA particles, it is not as highly pozzolanic as FA.[8]

7. SPECIFICATION REQUIREMENTS

Selection of the most appropriate FA for stabilisation purposes requires a different approach when compared with the selection of FA as a supplementary cementitious material. Australian Standard AS 3582.1[3] describes the general requirements for FA as a supplementary cementitious material for use with GP and blended cements. The accepted practice to date has been for specifiers to stipulate the use of FA that meets the requirements of AS 3582.1 when selecting material suitable for stabilisation work. It is often also assumed that the finest grade (with the lowest LOI) of FA is the best for application to modified and stabilised materials. That assumption would lead to an expectation that fine grades would perform better in a stabilisation role than the coarser concrete grades covered by the standard. This is not the case.

The test requirements of AS 3582.1 are set out in Table 2. It is apparent from a review of the available power station data that a wider acceptable tolerance would be useful in giving flexibility to the specifier. The inclusion of an additional grade for FA is currently being considered for inclusion in the next update of AS 3582.1.

In addition to those listed in Table 1 there are a number of other reportable properties including:

- Available alkali content
- Relative density
- Relative water requirement
- Relative strength
- Chloride ion content

Most Australian coal fired power stations have capability to produce fine grade FA through various processing techniques. Air classification is the most common and known as classified FA. Unclassified FA is known as ROS ash. The major difference between ROS ash and classified FA is the fineness.

Chemically there are no differences between classified and unclassified ash, however fineness related properties such as relative density, relative strength and relative water requirement will vary. A typical ROS ash would have fineness of at least 40% under 45 µm. The LOI is usually less than 6% however a few stations have higher LOI. The major impact of LOI in concrete applications relates to the entrainment of air. There are numerous other applications. For example, pavement stabilisation has no requirement for entrainment of air. Therefore, high or variable LOI is less important.

Grade	Fineness by mass % passing 45 µm sieve	Loss on ignition, % maximum	Moisture content % maximum	SO_3 content, % maximum
Fine	75	4.0	1.0	3.0
Medium	65	5.0	1.0	3.0
Coarse	55	6.0	1.0	3.0
Test Method	AS 3583.1	AS 3583.3	AS 3583.2	AS 3583.8

Table 2 Fly Ash Defined in AS 3582.1(3)

ROS ash is worthy of consideration for stabilisation uses. Based on the findings of Chapman and Youdale,(5) lime stabilisation of FBA produced an outstanding pavement material. Clearly FBA does not comply with the fineness requirements for AS 3582.1 but its other chemical properties are similar to FA. Research and testing is required to confirm the ability of ROS ash to improve the performance of the quarry materials in the same way that FBA performs. This is a worthwhile area for further investigation as the cost of ROS ash could be less than material specified in AS 3582.1.(3)

FA is captured, stored and delivered in a dry state in dedicated binder tankers whereas FBA tends to contain higher levels of moisture which needs to be considered during transport and further use. CCPs retrieved from storage (ie. ash dam) can have variable properties and need to undergo trialling and relevant testing prior to use.

8. APPLICATIONS

Stabilisation or modification can change some of the following attributes of pavement materials depending on the binder and quantity used. It may:

- Reduce plasticity
- Improve workability
- Increase strength gain
- Change particle size distribution
- Reduce the material moisture sensitivity
- Reduce permeability
- Alter the compaction properties
- Reduce required pavement thickness
- Dry out wet materials
- Improve work platforms

9 FIELD PERFORMANCE

9.1 M4 MOTORWAY

The Sydney M4 Motorway was widened from Prospect to Penrith over 15 months in 1997-98. The existing two lanes in each direction were widened to three lanes with the additional lane constructed along the shoulder using insitu stabilisation.(9) Insitu stabilisation was chosen because of the ability to achieve high production rates adjacent to one of Sydney's busiest motorways. The existing pavement material was recycled (asphalt and the original road base) which reduced the need to quarry virgin materials and the dispose of existing material.

Compared to conventional methods of pavement construction, an estimated 50,000 tonnes of road base material was recycled rather than going to landfill. This reduced both the cost and additional truck traffic that might otherwise have had to use the existing road. The binder used was 50% FA, 25% lime and 25% slag. The required 28 day strength of 2 MPa was achieved with only 3% binder by weight. The binder provided an extended working time to allow time to correct levels and improve compaction. Ongoing performance of the pavement has been reported to be satisfactory.(9)

9.2 EYRE HIGHWAY, SOUTH AUSTRALIA

In 1997, as part of a long term upgrade of the Eyre Highway between Port Augusta and Ceduna, a 33 km section of the highway near Kimba was widened.(10) The poor quality (high plasticity) of the locally available material meant it needed to be stabilised with a lime FA blend. Various mixes containing FA and lime were utilised and blended at a rate of 3% of the aggregate. The majority of the 33 km section utilised 2.5% FA and 0.5% lime. Figure 3 illustrates spreading of the binder before incorporation.

Port Augusta supplied the FA whilst the lime was obtained from Adelaide. The binder was selected to improve material stiffness and reduce moisture sensitivity (i.e. loss of strength due to seasonal wetting). In addition, it was desired to minimise shrinkage by using the blend in preference to GP cement as the binder.

Fig. 3 FA and lime blend, South Australia(10)

Transport SA lab tested potential shrinkage rates and found much reduced shrinkage from the lime and FA blend compared to GP cement. In addition, Transport SA reported that for the same binder contents, a 1:1 lime FA binder will provide an equivalent long term strength to cement.(11) Pavement performance was extensively monitored to verify the design approach. Falling

Weight Deflectometer testing over following years demonstrated that the performance of the stabilised blend was superior to the unmodified pavement.[11]

10. CONCLUSIONS

When unbound construction materials do not have sufficient strength or stiffness for a given application, modification or stabilisation of these materials with a small addition of binder can significantly improve performance and reduce costs.

The addition of binder increases the shear capacity of the pavement material and allows thinner pavements to be constructed. Layer thicknesses for compaction can usually be increased to provide further economy during pavement construction. The addition of binders to quarry materials can change the mechanical and physical properties of the blend.

The performance of the combined blend of source material plus the binder needs to be well understood before placement into a pavement structure.

CCPs, particularly FA, play a key role in binders chosen for stabilisation projects. Most importantly, they succeed by improving binder performance and reducing project cost. The choice of CCP should not be limited to the grades covered by Australian Standard AS 3582.1. Modification and stabilisation of road base pavement layers can be successfully carried out using ROS ash that has properties outside those specified in AS 3582.1.

Establishment of ROS ash as a modification and stabilisation aid will involve suitable trialling and testing to confirm the properties of the material. Long term tests will also be able to provide an indication of the likely load bearing capacity of the pavement and hence expected service lives. ROS ash thus can have a major impact on reducing costs of pavement construction where modification or stabilisation of existing material is required.

REFERENCES

1. Ash Development Association of Australia (ADAA), "Fly Ash Blended Binders for Road Stabilisation", Fly Ash Reference Data Sheet No. 7, , Available from http://www.adaa.asn.au, 2005, 2p.

2. Austroads, " Guide to Road Design", Austroads Publication No. AGRD01/10, Third Edition, Austroads Ltd, ISBN 978-1-921551-83-3, August, 2010.

3. Standards Australia, Australian Standard AS3582.1, "Supplementary Cementitious Materials for Use With Portland and Blended Cement – Part 1: Fly Ash", ISBN 0 7337 1688 1, SAI Global, 1998.

4. Evans, P., "Update on Lime Stabilisation" QMR Technology Transfer Seminar, 12 July 1997 Border District, Queensland Main Roads Lime Stabilisation Research Project, 1997.

5. Chapman, B.R. and Youdale, G.P., "Bottom Ash – From Industrial Waste to Pavement Material", Proceedings, 11th ARRB Conference, Vol. 11, No. 3, 1982, pp 90-105.

6. Ash Development Association of Australia (ADAA), "Australian Experience with Fly Ash in Concrete: Applications and Opportunities", Fly Ash Technical Note No. 8, , Available from http://www.adaa.asn.au/technicalnotes.htm, November, 2009, 4p.

7. Ash Development Association of Australia (ADAA), "Guide to the Use of Fly Ash in Concrete in Australia", Fly Ash Reference Data Sheet No. 1, Available from http://www.adaa.asn.au/refdatasheets.htm, August, 2009, 4p.

8. Heidrich, C., C. R. Ward, et al., Eds. (2007). Coal Combustion Products Handbook. Brisbane, Australia, Cooperative Research Centre for Coal in Sustainable Development.

9. Stabilised Pavements Australia, "M4 Motorway Project Report", Available from http://www.stabilisedpavements.com, March 2012.

10. Andrews, "Pavement Rehabilitation Report, Department of Transport, South Australia",, Materials Technology Section, Available from http://www.roadbondsoil.com/wp-content/uploads/2011/11/Australia%20-%20Eyre%20Highway%20Report.pdf, 1998.

11. Andrews, R.C. and Dey, A, "Economic Road Infrastructure Investment through In Situ Stabilisation, " Second International Conference on Ground Improvement Techniques, Singapore, 7 - 9 October, 1998.

ASH DEVELOPMENT ASSOCIATION OF AUSTRALIA (ADAA)

PO Box 1194 Wollongong NSW 2500 Australia
Telephone: +612 4228 1389 / Fax: +612 4258 0169
Email: adaa@adaa.asn.au / Web: www.adaa.asn.au