PAVEMENT CONSTRUCTION AND THE ROLE OF COAL COMBUSTION PRODUCTS

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1. INTRODUCTION

The use of Coal Combustion Products (CCPs) in road construction has been commonplace in Australia for many years. CCPs have been used in many of the elements involved in road construction and related applications such as filling of abandoned mines, structural embankments, low strength cementitious backfill, drainage systems, bridge components and pavements.

CCPs cover a range of materials. These can be broadly classified as follows:-

- Furnace Bottom Ash (FBA)
- Fly Ash (FA) conforming to AS 3582.1 Fine, Medium or Coarse grades ([1]), and
- Fly Ash not conforming to AS 3582.1 (often termed Run of Station ash or ROS ash)

This note describes the use of CCPs in pavement construction. In this note, the term FA has been used following the definition provided in AS 3582.1, a solid material extracted from the flue gases of a boiler fired with pulverized coal ([1]). Importantly the term FA is also used to cover material not conforming to AS 3582.1 specifications but still falling within the definition above.

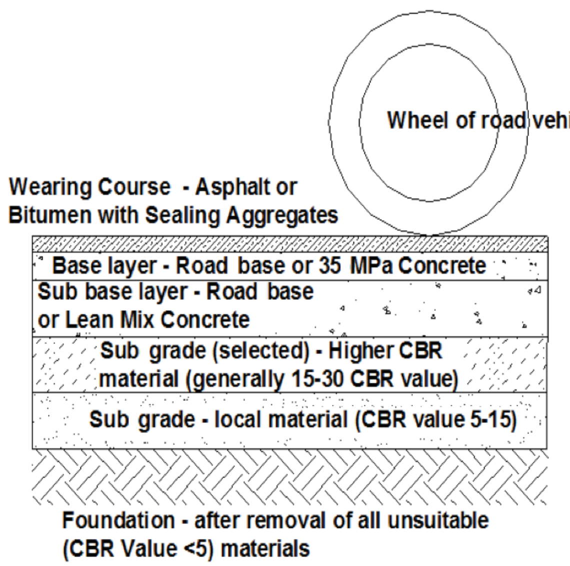

Fig. 1: Schematic Diagram of Pavement Layers in a Typical Pavement

2. PAVEMENTS DESCRIBED

2.1 GENERAL

The term pavement is normally used to describe the series of layers which form the structure of a road. Pavements may be flexible (asphaltic materials with granular layers) or rigid (cementitious concrete). Each layer provides important properties that assist in the distribution of stress from traffic loading to the ground beneath.

The structure of a road reduces the stress imposed on the ground or foundation by the wheeled traffic to levels that can be withstood. Roads and pavements need to be functional in wet and dry conditions. The pavement spreads wheel loads evenly to soil foundations and are designed to take wheel loads of varying intensity and movement numbers.

The series of layers forming a pavement is normally arranged with the strongest at the upper surface. Assuming the original ground is inadequate to support a design wheel load, a stronger layer “bridges” that ground. Each successive layer is designed to take load, such that the top level (which experiences the highest load) can provide a design service life. Figure 1 illustrates the typical layer structure of a conventional pavement.

The Australian Standards series AS 2758 covers the requirements for aggregates and rock for engineering purposes ([2]). Those more relevant to coal combustion products are Part 1, Concrete Aggregates ([3]), Part 2, Aggregates for Sprayed Bituminous Surfacing ([4]) and Part 5, Asphalt Aggregates ([5]). State road authorities utilise these standards and other specifications to determine acceptable road base requirements. These vary significantly on a State by State basis because of material variations. Australian Standards have not attempted to define any specific road base requirements as these continue to largely remain State based ([6], [7]).

2.2 PAVEMENT LAYERS

The uppermost layer of a pavement is the wearing course, shown in Figure 1. A typical pavement design may have up to 5 layers above the foundation level (the lowest layer shown in Figure 1). The wearing course directly carries the traffic and is the most highly stressed layer that is typically highly abrasion resistant, readily sheds water to designed drainage channels and resists penetration of water to lower levels. Immediately below the wearing course is the base layer, which can comprise of a stabilised granular layer for flexible pavement or concrete (typically having a compressive strength of 35 MPa) in a rigid pavement design. The base layer is the strongest part of the pavement. The base layer in a flexible pavement design can be a material stabilised using cement or lime to provide enhanced structural properties. Such materials fall under the broad classification of road bases that are defined as granular materials which when correctly placed and compacted form a stiff pavement layer in road construction ([6], [7]).

The next layer down is the sub base, which can be a road base material or a lean mix concrete, usually having a compressive strength at 28 days of 5 MPa. Beneath the sub base is a layer of select fill known as sub grade. This is usually won from a nearby quarry and is produced to meet a minimum performance level. Lower again is a sub grade that is usually produced from material excavated on the site during construction of the road. Finally there is the foundation layer, which is typically the original site material with topsoil and other low strength materials removed.

2.3 RIGID AND FLEXIBLE PAVEMENTS

The two major types of pavement design are rigid and flexible with each achieving a different design solution based on their method. A rigid pavement is very stiff, often comprising pre-mixed concrete. While higher in initial cost, it can have a much longer life and its objective is to achieve a lower overall pavement service cost. A flexible pavement is less stiff, allowing it to flex rather than crack under major loads. Within Australia flexible pavements tend to dominate the regional and rural road network because of their lower cost, however rigid pavements are common depending on the application.

3. PAVEMENT COMPONENTS

3.1 WEARING COURSE

The wearing course has a number of key functions. It must:-

- Allow water to freely drain from the driving surface to minimise aquaplaning
- Have a high skid resistance which is maintained over time, and
- Minimise moisture penetration to the lower structural layers of the pavement

In flexible pavements, wearing courses are normally spray seal, bituminous surfacing or asphaltic concrete. The asphaltic concrete can contain FA as a mineral filler. FA can aid in distributing the asphalt binder more evenly through the mix and improves grading of fine aggregate fractions to enhance physical characteristics.

With rigid pavements, conventional pre-mixed concrete is used to achieve a stiff and durable product. While concrete normally can have a higher capital cost, it normally achieves a longer service life. Rigid pavements may also be topped with asphalt for noise control. In this instance, FA is used in asphalt as a filler and in concrete as a supplementary cementitious material (SCM) ([8], [9]).

In all pavements, water penetration is the biggest threat to premature failure. When pavement layers beneath the wearing course are exposed to water they weaken. If loaded before the water is removed, permanent damage can result. Hence a waterproof wearing course and excellent subsoil drainage will reduce the risk of premature pavement failure.

3.2 BASE LAYER

The layer directly below the wearing course is described as the base layer which is a highly loaded structural layer. Typically it incorporates crushed rock or gravels that can be placed and compacted under the right moisture conditions to provide a stiff and stable support for the wearing course. The base layer would normally comprise of a blend of specially selected aggregates and finer materials. To minimise transport costs, gravels and aggregates are generally quarried near the site of the road construction. If local materials are inadequate for the intended application, they can be modified or stabilised by the use of additional materials. Imported materials are normally more plastic (i.e. contain clay bearing minerals), cementitious, or pozzolanic (they harden in the presence of lime).

Base layers are often made with concrete having a compressive strength around 35 MPa in addition to other criteria such as flexural strength. Details on FA concretes are available in the technical literature ([8], [9]). In flexible pavements, FA is commonly used as an additive where it forms part of a binder as a cement stabilised material or is lime stabilised. A cement stabilised base course will utilise FA as part of the binder in proportions typically 70:30 cement to FA.

Cement used alone as a stabilising binder tends to harden rapidly for pavement applications (typically hardening in a couple of hours following placement) and thus needs to be designed taking this factor into account. Construction typically requires sufficient time for placement and compaction of the road base into the pavement. FA can be blended with the cement to slow the rate of early hydration and thus allow time for placement and compaction of the road base. The compacted FA/cement blend continues to react to stiffen the base layer. Blends of FA and lime are commonly used in the construction of flexible pavement base layers. The FA and lime binder react slowly and gain strength over longer periods of time such that their structural capacity improves. In operation, the base layer will be subject to repeated cycles of loading and unloading and it has to be designed to resist such cyclic loading without deformation over time.

The pavement life is usually designed in terms of the number of cycles of loading and unloading. The measurement of load cycles is based on the concept of the Equivalent Standard Axle (ESA) which represents a load of 80 kN on a single axle distributed over 4 truck tyres (2 pairs). Typical design criteria might be 10^6 ESA's over a 20 year life without failure.

3.3 SUB BASE LAYER

The layer below the base layer is the sub base layer (Figure 1). This layer is normally deeper in the pavement than the base and hence is not as highly loaded as the base. As such the sub base can contain larger quantities of fine crushed rock or other fine material. Given appropriate moisture conditions, these layers can be bound into a suitable load bearing and stable platform to support loads transferred from the base layer. If the sub base material strength is inadequate for the imposed load, it can be stabilised in a similar manner to the base layer using appropriate binders. Both the base layer and the sub base layer can range in depth depending on design requirements. For the same set of materials, a thicker layer will have greater ability to take load when compared with a thinner layer.

For heavy duty road construction, the designer may choose a concrete pavement, where a base concrete is specified with a compressive strength of approximately 35 MPa. This base can be placed over a sub base layer typically having a 5 MPa compressive strength (known as lean mix sub base concrete). In this case the lean mix concrete provides support to the base by bridging the layer between the lower sub grade and foundation layers and the concrete base. The base concrete may be designed to be unreinforced, reinforced, having fibres or post-tensioned. Lean mix sub base layers can contain high proportions of FA in the binder ([10]).

3.4 SUB GRADE LAYER

The layer below the sub base is generally made up of a range of materials either won at the construction site or imported. These are often referred to as sub grade materials and can have a range of requirements depending on how far beneath the base layers they are positioned. Such a layer would need to be carefully designed in conjunction with other drainage paths outside the pavement area to ensure water flows were away from the pavement. For sub grade and foundation materials, a commonly used criterion for design known as the the California Bearing Ratio, (CBR is used). This is a strength test that measures the ability of the material to hold load under pre-specified extreme conditions ([11]). CBR can be tested when a material is at its optimum strength, or for a more realistic measure, it can be "soaked". The soaked CBR indicates the strength of the material when saturated with water, often for several days before the test. The higher the CBR value, the less material is generally required in the layers above, reflecting an increased bearing capacity of the material.

In general, most road authorities would specify construction materials with a higher CBR value as they approach the surface of the pavement construction, where the traffic loading is higher. FBA has been reported to have a CBR value which is higher when soaked than dry. This is an unusual and valuable property which makes it an especially useful material to build into a drainage layer as described above ([12]).

4. COAL COMBUSTION PRODUCTS USED IN PAVEMENT CONSTRUCTION

FA and FBA can be used in every pavement layer above the foundation layer and in various ways. Particle sizes for FA range from less than 1 micrometre (μm) to 200 μm and are irregular to spherical in shape. FA is pozzolanic in nature, that is, it reacts with calcium hydroxide in the presence of water to form cementitious compounds. FA is typically used in the manufacture of concrete and hence is commonly used in sub base or base courses as part of a concrete mix ([8], [9]).

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 for disposal. FBA can comprise 10-20% of the coal combustion products produced from a power station and ranges in size from less than 300 μm to 5 mm in size. It has a chemical composition similar to FA but may contain greater proportions of carbon and is relatively inert. The coarse particles make an excellent free draining fill and so are very beneficial as a drainage layer. FBA has been used in large quantities in Australia and other countries as structural fill in asphalt mixes and for other civil engineering purposes. The high permeability of FBA makes it an especially useful material for application in sub grades where one design option is to incorporate a layer of FBA immediately below the sub base. This drainage layer would need to be designed to allow groundwater or other sources of moisture to drain by gravity away from the pavement.

The use of CCPs in road construction has been common in Australia for many years. There is extensive use of FA in concrete and information on this has been published elsewhere ([8], [9]). The end of the 1980's saw the construction of full depth FA pavements at Northern Power Station in South Australia. Subsequently large scale research work undertaken at Eraring power station in NSW in the mid 1990's included a trial using Austroad's Accelerated Loading Facility (ALF) on a FA pavement. In addition several pavements were constructed on access roads to and from the power station to allow real traffic testing to occur. These projects were successful and the pavements are currently in operation. The "Guide to the Use of Fly Ash and Bottom Ash in Roads and Embankments" published by ADAA ([13]) contains extensive design information relating to CCPs in pavements.

In the early 1980's, the Roads and Maritime Services of NSW (RMS) investigated the properties of FBA from Munmorah power station in NSW. Chapman and Youdale showed that stabilised FBA has the potential to be a lightweight material of great strength when properly utilised ([14]). A number of key properties were identified in this project, with particular note made that the FBA in its natural form was an excellent free draining fill material. One notable observation related to the stabilisation of the FBA with lime. Results with as little as 2% lime showed the FBA could achieve over 2.5 MPa at 28 days. Other tests revealed some of the unique physical properties of FA including those which are common to most power station furnace ashes. They reported that the material was non plastic, had a maximum dry density of 1.06 t/m3 and a CBR of 70% ([14]).

In 1992, the previous owners of Eraring, Pacific Power, in conjunction with the NSW RTA, Lake Macquarie City Council (LMCC) and the University of Technology Sydney, initiated a $1.2 million R&D project to investigate ash use in road construction. The 1997 version of the 'Guide to the Use of Fly Ash and Furnace Bottom Ash in Roads and Embankments' was one of the major outputs of this project ([13]).

The ARRB conducted accelerated loading testing using an accelerated loading facility (ALF) on the Eraring pavements ([15]). To provide ongoing information, several pavement areas on public roads were reconstructed using CCPs with skills and techniques that were developed in the project. Two "on- ramps" that channel road traffic leaving the power station onto the local main road MR217 were reconstructed in 1993 after the ALF trial. The northbound "on-ramp" was reconstructed using cement stabilised FA as an overlay. The depth of the overlay was approximately 300 mm. This ramp has been in service since September 1995 and its performance to date has been reported to be satisfactory. The southbound "on-ramp" was widened by insitu stabilisation of the shoulders to a depth of 300 mm using a 10:25:65 (%) cement:lime:fly ash blend as the binder. The traffic lane of the southbound "on-ramp" was boxed out to an approximate depth of 450 mm for a pavement comprising a cement stabilised FA base with 8% cement placed using conventional road construction plant.

5. CONSTRUCTION ISSUES

Due to the small particle size and light weight nature of CCPs, their inclusion in materials for construction of pavements needs to be carefully designed to assure success. The major hazard is dust in hot or dry conditions where materials dry out with dust becoming airborne during the construction phase. To minimise this risk the materials should be:-

- Kept moist
- Drained to minimise erosion
- Compacted as soon as practicable after placement, and
- Capped with a soil cover if not being stabilised

It is important to ensure suitable traffic regulation during the construction phase to minimise evolution of dust. It is also important not to use excess water which may mobilise the FA and cause runoff into nearby water courses.

6. CONCLUSIONS

The benefits of the use of CCPs in road pavements are still not well understood by the wider construction industry. In Australia, FA has been and is being extensively used in concrete and concrete products. It is also a preferred material for use in modifying and stabilising road pavement materials. FA is likely to be increasingly used for pavement construction as knowledge of the material is increasingly widely applied. FBA, due to its coarse nature, is also finding a wider acceptance as a pavement construction material where it is available for use.

For a material to be suited for pavement construction it must be able to be compacted into a hard relatively impermeable layer, which will resist deformation under cyclic loading. Both FA and FBA have a role in modifying the mechanical properties of pavement materials, either by improving the grading, density or compactability of the blend materials or by virtue of the pozzolanic properties of FA.

Both FA and FBA have proven to be suitable for use in road pavements in a number of different applications. By using different proportions of FA and FBA, a range of different material properties are achievable and when designed and constructed properly, pavement layers containing these ash products have performed well under traffic over time. CCPs are proving to be valuable resources in the construction of road pavements.

The availability and performance of these products make them valuable inclusions in products for pavement construction. The use of CCPs helps to sustain our ever diminishing natural resources. As knowledge of the valuable properties spreads, use of CCPs in pavement construction will grow.

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