Ash Development Association of Australia

Fly Ash Reference Data Sheet NO. 10
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ROLLER COMPACTED CONCRETE AND THE ROLE OF COAL COMBUSTION PRODUCTS

1. INTRODUCTION

Roller compacted concrete (RCC) is a Portland cement concrete that is placed using construction techniques normally associated with earthworks rather than slipforming or formed construction techniques used for rigid concrete structures. RCC can be considered as a construction method rather than a new material with its economic savings mainly arising from a reduction in construction costs rather than in material costs. ([1])

RCC is commonly used for the construction of major dams in Australia with limited use in pavement construction. This concrete mix uses much lower rates of water addition compared to normal grade concrete mixes, the compaction process is critical to achieve a tightly bound matrix that can then be allowed to cure. Coal Combustion Products (CCPs) have an important contribution technically and environmentally in RCC construction. Fly ash (FA) is used as a key element of the binder to slow the rate of reaction, allowing time for placement and compaction of the RCC.

2. BACKGROUND

A normal class concrete is one of the categories specified under AS 1379 ([2]). One of the major specification requirements is slump, which for normal class concretes ranges from 20 mm to 120 mm. Slump is principally controlled by the water content of the mix, where Water Reducing Admixtures (WRA) may also be involved. RCC is generally specified as Special Class Concrete with essentially the same ingredients as a Normal Class Concrete but having specific properties ([2]). As its intended method of placement is with earthmoving plant such as graders, it has a lower water content than Normal Class Concrete having a typical 80 mm slump.

RCC has a low workability with essentially no slump. This is the major difference when compared with normal concrete ensuring it can be placed using external compaction. Normal concrete is highly workable and requires internal vibration to achieve a dense and void free matrix. The placement of RCC uses similar methods to those used to place paving material and road bases. RCC is delivered by dump truck or conveyor and spread by small graders or specially modified asphalt pavers. The final placement is to compact the RCC using large vibratory rollers. Figure 1 shows a typical spreading operation using a grader.

Fig. 1: Grader used to Spread RCC ([3])

As with the use of FA in normal concretes to form part of the binder, RCC makes use of FA as a supplementary cementitious material (SCM) ([4, 5]). RCC contains cementitious binders (cement and FA), water, sand, aggregate and admixtures. The mix uses much less water than conventional normal class concrete. Various roads authorities have definitions of RCC. For example the Roads and Maritime Services of NSW (RMS) in QA Specification 3221 (QA Spec 3221) define RCC as "A relatively dry concrete mix with very low slump and compacted using smooth drum rollers". FA, as a result of its characteristics and particle size can improve the workability of RCC at these low slumps with corresponding improvements in compactability ([4, 5, 6]).

3. CONSTRUCTIONAL AND DESIGN CONSIDERATIONS

3.1 CURING TIME

The need to spread and compact the material requires a longer curing time when compared with normal concrete. The partial replacement of cement binder with FA can produce slower set times and extended working time to facilitate placement and finishing. Care should be taken in cooler climates as temperatures below 15^{0}C can further extend concrete set times ([4]). The need to achieve compaction before significant binder hydration means that there is a critical time within which placement must be completed.

In 1988, RCC pavement trials were conducted by VicRoads, the Australian Roads Research Board (ARRB) and the Cement and Concrete Association of Australia ([1]). In that study, one (1) kilometre of RCC pavement was constructed in Melbourne. This pavement utilised general purpose cement as a binder and identified a relationship between density and strength of the finished RCC. A number of laboratory trial mixes were undertaken to determine the best design for the full scale pavement. Over a range from 100% to 96% of Modified Maximum Dry Density (MDD), the 28 day strength of the trial mixes varied from 35 MPa to 53 MPa ([1]). It was found that each 1% decrease in density from 100% reduced concrete compressive strength by 4.5 MPa. With the high sensitivity of strength to density, it was clear from these trials that a mechanism was needed to retard the set for long enough to allow placement and compaction. FA could be used as part of the binder to assist in retarding the initial set. This could allow adequate time for placement and compaction to be completed.

3.2 PLACEMENT THICKNESS

The placement method requires density to achieve the required strength. As such, compaction is a critical part of the construction process. Heavy rollers are used to achieve the required compaction. In any earthworks project, it is not generally recommended to attempt to compact layers that are thicker than 300 mm. For example, if the design requires a pavement of 600 mm thickness it will have to be placed and compacted in at least two stages to ensure the compaction is achieved through the full depth of the material. The use of multiple layers of RCC also raises the problem of layering. A potential weakness exists between the layers because of a lack of bond between them.

The ideal situation is where the layers bond together to form a single uniform mass. Typically this requires subsequent layers to be placed shortly after the first layer. Because of the difficulty of placing consecutive layers and achieving bond, it is common practice to place a thin slurry layer (typically 3:1 cement:water) on top of the first RCC layer. This slurry layer can be applied after compaction and testing is complete so it is still active when the second RCC layer placed. Achieving satisfactory bond between the two layers remains a critical construction issue ([1]). The key placement requirement is to achieve sufficient density to ensure the development of adequate strength in the RCC mix. The compromise between bonding of multiple layers and the ability to compact thick single layers will influence the adoption of RCC technology more widely.

3.3 PERMEABILITY

Saturation of an RCC mass can lead to a reduction in strength. To limit any risks, the RCC layers need to be resistant to water penetration. In the case of a dam it is normal practice to face the structure with formed in place normal concrete, to protect the internal RCC. When FA is added to normal concrete, one of the benefits is a less permeable hardened concrete ([6, 7, 8]). The FA produces a denser pore structure within the concrete and contributes to a less permeable matrix through its size fraction thus reducing the water demand of the concrete. As well as providing the benefit of delayed setting times in RCC, FA could also be expected to reduce permeability in the same way that it does in normal concrete ([6, 7, 8]).

3.4 ALKALI AGGREGATE REACTION (AAR)

Alkali Aggregate Reaction (AAR) is a deleterious reaction occurring in concrete when reactive aggregates are used in the mix. FA addition to normal concrete is widely recognised in Australia as a solution to AAR ([4, 8, 9]). RCC projects can often be located in a moist alkali rich environment that might potentially encourage AAR expansion. Use of FA within the RCC will provide resistance to any likely expansion ([8, 9]).

4. RCC AND FLY ASH

4.1 AUSTRALIAN STANDARDS

FA is a solid material extracted from the flue gases of a power station boiler fired with pulverised coal ([10]). Particle sizes range from less than 1 micrometre (μm) to 200 μm and are irregular to spherical in shape. Selection of the most appropriate FA for an RCC mix requires a slightly different approach when compared with selection of FA as a SCM. Australian Standard AS3582.1 ([10]) describes the general requirement for FA as a SCM for use with General Purpose and blended cements. When used in concrete, the requirements for FA are set out in Table 1. It is apparent from a review of the available power station data that a wider acceptable tolerance would be useful and gives flexibility to the specifier. An additional grade providing for Run of Station FA is currently being considered for inclusion in the next update of the standard.

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 1: From Table 1 of AS 3582.1 ([10])

In addition to properties 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 of these properties are unlikely to be critical in an RCC mix where the key interactions are physical. With no reinforcement present, chloride ion content will also not be relevant. In the absence of alternative standards, most specifiers will use AS 3582.1 specifications when considering material suitable for RCC work. RCC is usually mixed in a site based pugmill rather than a batch plant and this places different constraints on the required products.

For concrete, the finest grade of FA is usually the most appropriate from a reactivity, strength gain and mix economy perspective ([4, 5, 8, 9]). This is not necessarily the case for RCC as a coarser grades of FA as described in AS 3582.1 and material that does not conform to AS 3582.1 requirements may also provide benefits.

The choice of FA selected for an RCC mix should be one with a low variability so that the properties of the mix are consistent. The absolute level of unburnt carbon in the ash (as measured by Loss on Ignition - LOI) is critical in normal concrete, where air entraining products are used and, but less so with RCC. Most modern power stations have LOI of less than 5% ([11]). The major impact of LOI in concrete applications relates to the entrainment of air and product consistency. There is no requirement for air to be entrained in an RCC process so higher LOI can be acceptable. This makes all grades of FA in AS 3582.1 and material not conforming to AS 3582.1 potentially suitable for RCC applications. It is important with any RCC component such as FA, that it provides suitable workability to the concrete. This is necessary to ensure the strength gains resulting from correct placement and compaction are achieved. This would normally be confirmed by suitable research, trialling and testing.

4.2 FLY ASH PROPERTIES

In a 2007 report prepared for the CRC for Coal and Sustainable Development ([11]), the CSIRO examined the variation in FA characteristics of the ash from 16 Australian power stations. The identities of the stations were not revealed, but could be determined from information contained within the report. Table 2 describes the range of properties for FA from NSW, QLD, SA and

WA. The data relates principally to ash that has not been classified with single samples from each site. For comparison purposes, a number of furnace ash samples have been included in the table. While the report describes significant variations in the chemical composition and the physical structure at a microscopic scale, the particle size properties listed are remarkably consistent between the different sites.

Power station (State)	Type	Fineness % passing 45 µm	Loss on Ignition %
Port Augusta (SA)	FA	86	0.3
Mt Piper (NSW)	FA	91	0.76
Vales Point (NSW)	FA	68	2.78
Eraring (NSW)	FA	88	1.36
Liddell (NSW)	FA	75	5.72
Swanbank (QLD)	FA	60	3.87
Gladstone (QLD)	FA	85	4.71
Muja (WA)	FA	85	2.68
Kwinana (WA)	FA	75	3.39
Bunbury (WA)	FA	84	4.31
Munmorah (NSW)	FBA	10	-
Callide (QLD)	FBA	12	-
Tarong (QLD)	FBA	8	-
Gladstone (QLD)	FBA	6	-

Table 2: Australian Fly Ash and Furnace Bottom Ash Properties (6,11)

4.3 SPECIFICATIONS

In NSW, the former Roads and Traffic Authority, now Roads and Maritime Services published a range of QA Specifications (4). QA Spec 3221 itemises the requirements for RCC used in pavements in three different grades based on compressive strength, they being

- RCC5
- RCC10
- RCC20

This specification requires any included FA to meet the quality requirements set out in QA Spec 3211, which in turn requires FA quality to satisfy AS 3582.1 SCM for use with Portland and blended cements. (10). Similar requirements are also called up in many of the Government Authority specifications for RCC. In general RCC, it contains a different range of aggregate sizes than conventional concrete mixes. They are designed to be placed by compaction therefore the gradings resemble a road base pavement rather than a concrete. The aggregate improves the material interlock of the RCC and subsequently the shear strength of the layer after compaction. The binder content is relatively low and contains significant percentages of FA to develop the low to moderate strength over a long timeframe. In this way, the development of insitu stiffness of the RCC is managed and block cracking due to a slightly more rigid layer is minimised. Control of RCC moisture content during placement is very important as with road base materials. This enables compaction to achieve adequate insitu density in each material layer.

5. FIELD PERFORMANCE AND APPLICATIONS

RCC has been commonly used in a number of dam projects since the mid 1980's. In this application, it is gaining status as a preferred technology for modern dam construction, giving a smaller embankment volume than earthfill, but a quicker construction time than formed structural concrete. An example of an RCC dam and an RCC pavement are given below.

The Victoria Dam near Perth was originally built in the 1890's. To increase its capacity it was rebuilt in 1990 and was only the fifth RCC dam to be built in Australia. It utilised 121,000 m^3 of RCC with FA sourced from Muja power station. The cement used was a combination of GP at 24 kg/m^3 and slag at 203 kg/m^3 (12) with FA included as part of the binder. The 121,500 m^3 of RCC that makes up the dam was produced on site using a pugmill with placement occurring around-the-clock over a period of 4 months. Construction of the dam core was a bulk earthworks-type operation with the RCC spread and compacted using bulldozers and conventional rollers.

The Tarong access road was completed in 1991 as a reconstruction of a 3.4 km section of pavement. The pavement provided access to the power station for pneumatic tankers collecting FA for commercial sale (1). Initially a 300 m trial was successfully completed which led to the full project in 1991. The RCC was a single layer placed over the top of a cement treated sub base. Two thicknesses were tried in the test project. In the final project, 170 mm thick RCC was placed on top of 125 mm cement treated sub base. The design F'c of the RCC was 40 MPa, and the binder content was 240 kg cement, 80 kg FA (3).

6. CONCLUSIONS

FA is a well known and technically acceptable SCM for use in RCC. As an alternative to fine grade FA complying with AS 3582.1, other grades of FA should be considered in this application provided testing confirms required outcomes such as strength and minimum variability. FA is a cost effective material that improves the placement and handling properties of RCC mixes when compared to Portland cement alone.

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