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USE OF A HIGH SHRINKAGE AGGREGATE IN A NEW RCC DAM

Damian Nott
GHD Pty Ltd for Bulk Water Alliance, Australia, dnott@ghd.com

Brian Forbes
GHD Pty Ltd for Bulk Water Alliance, Australia, bforbes@ghd.com

Daryl Brigden
Australia, darylbrigden@bigpond.com

SUMMARY

The Enlarged Cotter Dam is a new 85m high RCC dam currently under construction in Canberra, Australia. It will be Australia's highest RCC dam. The closest available source of aggregate for the dam's construction was a Rhyolite that does not meet the Australian Standard for conventional concrete aggregates (AS2758.1). The source rock has sustained significant geothermal alteration, which together with weathering results in an aggregate that exhibits high wet/dry strength variation and dimensional instability (i.e. shrinkage characteristics). The aggregate produced concrete with significant drying shrinkage potential and it was unclear whether it would be suitable for use on the exposed faces of the dam.

This paper reports the results of the trials and testing undertaken to investigate the performance of the GERCC produced from the local aggregate. Several recognized test procedures were undertaken and new test methods were also developed. The results enabled GERCC to be used and significant savings to be made. With the dam's construction now largely complete, early age field performance of the GERCC facing is also reviewed.

1. INTRODUCTION

Enlarged Cotter Dam is a new 85m high RCC dam currently under construction in Canberra, Australia. It will be Australia's highest RCC dam. Approximately 390,000 m^3 of RCC will be used in its construction. The dam will serve to augment the city's water supply. It is being built approximately 100m downstream of the existing 35m high Cotter Dam. The new dam will increase the storage capacity of the existing reservoir from 4Gl to 78Gl.

The best available source of local aggregate for the construction of the dam was a local Rhyolite, notwithstanding that it had sustained significant geothermal alteration. As a result of this alteration and weathering the Rhyolite exhibits high wet/dry strength variation and dimensional instability (i.e. shrinkage characteristics). The aggregate produced concrete with significant drying shrinkage potential.

With concerns regarding durability, consideration was given to facing the dam with a conventional concrete made from imported aggregate which satisfied all national code requirements. Significant cost savings were however available if the local aggregate could be used, which also better satisfied the projects sustainability objectives. Facing concrete in the form of Grout Enriched RCC (GERCC), using all local aggregates, was therefore investigated alongside conventional concrete mix designs, using all imported aggregates.

The properties of the aggregate are described along with the potential limitations for its use. A selection of the trials and testing undertaken are presented as a case study. The technical issues associated with dimensionally unstable aggregate are explored. Various testing techniques are described throughout the report, some of which may be beneficial for use on other projects. With the dam's construction now largely complete, early age performance of the GERCC facing on the dam itself is also reviewed.

2. AGGREGATE SOURCES AND PROPERTIES

2.1. GEOLOGY

The main dam site and quarry are located within the late Silurian Walker Volcanics, a shallow intrusive rhyolite deposit. The rockmass has been geothermally altered to varying degrees. The alteration produced a significant percentage of secondary minerals, including chlorite and smectite. An amorphous content (predominantly clays) is also present and varies depending on the extent of weathering.

The depth of weathering in the quarry meant that approximately 7m of material had to be spoiled if only Slightly Weathered or better material was used, (a requirement that would likely have been adopted if it were a commercial aggregate quarry). An alternative quarry site was identified; however it contained more variable material from a pyroclastic source and was therefore not preferred. Material won from excavation of the main dam foundation was a possible additional source of aggregate. Only 13% of this material was however estimated to be Slightly Weathered or better.

Considerable savings could therefore be made if a percentage of weathered material could be used.

2.2. PROPERTIES

The typical requirements of conventional concrete aggregates (such as outlined in AS2758.1) were used as the starting point for the assessment. The aggregate satisfied most of the criteria (depending on the extent of weathering) including Los Angeles Abrasion and Sodium Sulphate Soundness, but failed the following criteria:

- Material finer than 2um < 1%. Results for the site manufactured sand ranged from 2.5% to 4.5%.
- Wet Dry strength variation < 35%. Weathered samples had a wet/dry strength variation of up to 60% and highly altered fresh material was up to 45%. Fresh unaltered material was as low as 12%.

The saturated surface dry density of the sand ranged from 2.5t/m3 and 3% absorption (weathered) to 2.65t/m3 and 2.2% absorption (fresh). The rock fines were found to be non-plastic (Plasticity Index <3). For the coarse aggregate the particle density ranged from 2.55t/m3 to 2.68t/m3 and absorptions ranged 0.6% to 1.6%. The elastic modulus of the rock ranged from 15GPa to 70GPa depending on weathering.

Other testing was also undertaken to better understand the aggregate properties. Details of these tests and key findings are presented below.

2.2.1. ROCK SHRINKAGE

Amongst other factors, concrete shrinkage is a function of aggregate shrinkage [2,3]. To investigate the possible dimensional instability of the aggregate Rock Shrinkage testing was done to the Melbourne Metropolitan Board of Works (MMBW) standard. The testing showed that the degree of rock shrinkage was highly dependant on the extent of alteration and weathering. A relationship was also found to exist between Rock Shrinkage and wet/dry strength variation, as well as with Methylene Blue Value (refer Section 2.2.2).

Rock shrinkage testing was found to be a useful tool for initial appraisal of the potential rock source. It allowed discrete samples to be tested so the issues could be clearly understood, then extrapolated based on the geological model. This information could be obtained from small core samples early in the investigations, without obtaining bulk rock quantities for wet/dry strength testing (e.g. lots of core or large test excavations).

The alteration caused discolouration of the otherwise grey rock. The pink and red altered material exhibited the greatest shrinkage. A degree of selective sampling was therefore possible simply based on colour.

2.2.2. METHYLENE BLUE VALUE

Recent research has found Methylene Blue Value (MBV) testing [5] to be a good indicator test for the effects of mineralogy and the performance of manufactured sands in concrete. The water demand of concrete mixes has a correlation with the product of MBV and percentage rock fines. A recent industry publication recommends that this product be limited to 100 or less for manufactured sands used in concrete [1].

As the site manufactured sand could have a rock fines content of around 16%, the MBV needed to be less than 6 to comply with the CCAA recommendation. MBV's of up to 9.5 were obtained for the altered and weathered rock.

Parallel MBV and rock shrinkage testing found there to be a good correlation between the two. Having this information meant MBV's (which are quick and easy to do) could be used as a control test during production whilst providing a good indication of rock shrinkage and wet/dry strength variation at the same time.

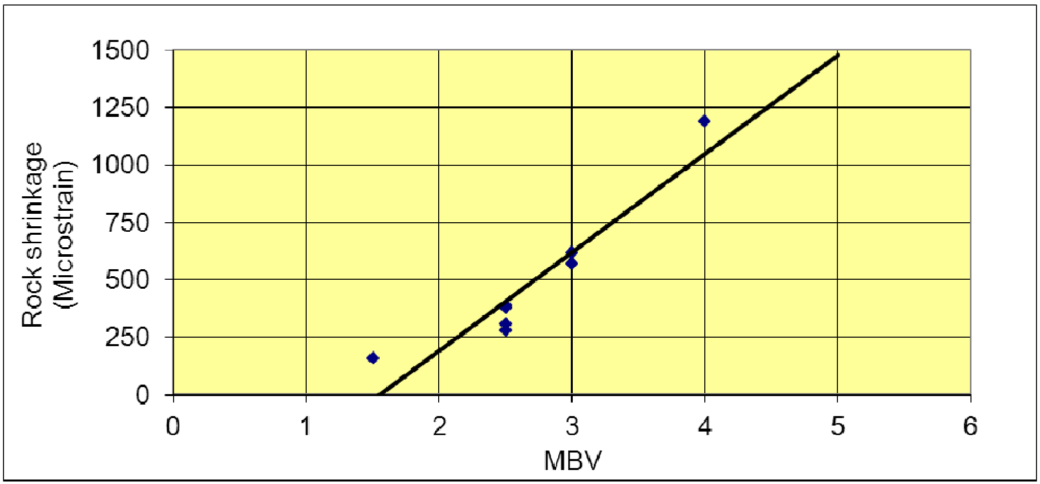

Fig. 1
MBV versus Rock Shrinkage

2.2.3. ETHYLENE GLYCOL

The aggregate was tested in Ethylene Glycol in accordance with CRD-C148-69. Ethylene glycol reacts with clays of the montmorillonite group to cause swelling. When such clay is present in sufficient quantities in rock, the expansion will be sufficient for breakdown of the rock to occur. This test provides an indication of what breakdown could occur when exposed to repeated wetting and drying or freezing and thawing conditions, such as could occur in nature over long periods of time.

From the testing undertaken, none of the specimens showed signs of breakdown including altered and moderately weathered aggregate samples. This is a very useful method of testing where there is a known or suspected presence of montmorillonite.

2.2.4. EXISTING DAM

The existing Cotter Dam was originally constructed in 1915. It was raised in 1951 to its final height of 35m and was post tensioned in 1998. Both the original construction and the raising were undertaken using concrete containing coarse aggregate from the same rock unit. Imported sand was however used. Fully imported commercial aggregates were used in the concrete used in 1998.

The concrete used in all campaigns has performed well, with no obvious signs of undue deterioration. This provided some confidence in the coarse aggregate, albeit when used with a natural sand.

3. LABORATORY TRIALS AND TESTING

To investigate the likely performance of the GERCC, several mixes were produced in the laboratory for testing. Conventional concrete mixes were also prepared for comparison, one of which was a replica of the concrete used on the existing dam in 1998. Cores from the original dam were also taken (both from the original concrete (1915) and from the upgrading).

As much of the testing undertaken was unusual or unique, there was often no reference pass/fail criterion. The range of mixes was therefore essential for comparison.

4. MIX DESIGNS

Details of the mixes used in the trials are presented in Table 1 below.

Table 1
Concrete Mix Details

Type	Name	Cement (kg/m3)	Flyash (kg/m3)	Water (kg/m3)	Description
GERCC	GE151	131	98	170	15MPa GERCC. RCC plus 67L of superplasticised grout with a water/cement ratio of 0.9
	GE252	148	98	164	25MPa GERCC. RCC plus 60L of superplasticised (double dosage) grout with a water/cement ratio of 0.6
	GE253	148	98	164	25MPa GERCC-m with air. RCC plus 60L of superplasticised (double dosage) grout with a water/cement ratio of 0.6 and air entrainment.
Conventional Concrete	CVC101	90	110	135	10MPa* conventional concrete
	CVC102	90	110	135	10MPa* conventional concrete, with site won coarse aggregate
	CVC201	170	85	150	20MPa* conventional concrete
	CVC302	250	80	170	32MPa* conventional concrete, air entrained. Replica of concrete used to upgrade existing Cotter Dam (1998)
Core Samples	CTR_1915	unknown	unknown	unknown	25MPa conventional concrete.
	CTR_1998	250	80	170	32MPa* conventional concrete, air entrained. Concrete used to upgrade existing Cotter Dam (1998)

Notes
- Strength is at 180d unless marked with "*"
- All GERCC samples are made from entriely site won aggregates
- All conventional concrete mixes are made from entirely imported aggregates, unless noted otherwise

All of the GERCC mixes were prepared using a common parent RCC as the base material and adding grout of different mix proportions. The RCC was a “high paste” RCC mix containing, 85kg of cement, 105kg of fly ash and approximately 120L of water per cubic metre of RCC. The aggregate was produced from a trial quarry, in the proposed quarry location.

The conventional concrete mixes were made using fully imported aggregates. This was done to enable comparison of GERCC with CVC facing concretes produced from likely local commercial sources. CVC102 was the exception, where site coarse aggregates were used. Aside from the site aggregates, this mix is otherwise identical to CVC101. It was prepared specifically to investigate the effect the site coarse aggregate is having on performance, as distinct from the manufactured sand component.

Conventional concrete mixes CVC101, 102 and 201, were stiff mixes, superplasticised for workability. They were designed specifically as facing mixes with a high aggregate content and low slump to allow interface compaction with the RCC. CVC302 replicates the "30MPa" conventional concrete used when the existing dam was post-tensioned in 1998. CTR_1915 and CTR_1998 are cores taken from the original dam. These were taken from the original concrete (1915) and the post-tensioning, respectively.

5. RESULTS

5.1. STRENGTH

The strength results are presented in Table 2 below. CVC102, which contains coarse aggregate from on site, is considerably weaker than its equivalent containing fully imported aggregates (CVC101). This suggests the coarse aggregate is having some negative effect on strength.

Table 2
Compressive Strength Results

		Strength			
Type	**Name**	**28d**	**180d**	**360d**	**Core**
GERCC	GE151	13.9	31.5	-	
	GE252	17.3	41.0	51.0	
	GE253	17.4	41.0	51.8	
Conventional Concrete	CVC101	14.6	35.9	42.7	
	CVC102	9.0	21.8	-	
	CVC201	26.6	42.5	47.7	
	CVC302	35.3	48.8	58.4	
Core Samples	CTR_1915				25.0
	CTR_1998				36.0

5.2. SHRINKAGE

Drying shrinkage testing in accordance with AS1012.13 was undertaken and the results are presented in Table 3. This test uses concrete prisms of 75mm square cross section by 280mm long. After 7 days of water curing, the specimens are stored in a drying room at 23˚C and 50% humidity for 56 days.

The limit for “Normal-Class” concrete, as defined by AS1379, is 1,000 microstrain after 56 days drying.

All of the conventional concrete mixes had shrinkage of approximately 700 microstrain at 56 days, significantly less than the GERCC mixes. CVC102 had very similar drying shrinkage to CVC101. This indicates that the coarse aggregates are not the major contributor to the overall drying shrinkage of the GERCC.

GE151 has the greatest drying shrinkage, as could be expected given it has the highest water content and water/cement ratio. Its drying shrinkage is 1400 at 56 days, which exceeds the ‘normal class’ concrete limit by 40%. GE252 and GE253 have a drying shrinkage of approximately 1150 microstrain. This is distinctly better than GE151, but still exceeds the standard (by 15%).

To investigate what impact an extended period of water curing has on drying shrinkage potential some samples were water cured for 56 days before being dried to constant mass in an oven at 65°C. These results were compared with those that were water cured for only 7 days (as per AS1012.13) and are also presented in Table 3.

Table 3
Concrete Drying Shrinkage Results

	Testing to AS1012.13 (7 days water cured)		Additional Testing (water cured for 56 days, then oven dried at 65°C to constant mass)		
				Reduction (compared to 7d curing)	
Type	**Name**	**Shrinkage (με)**	**Shrinkage (με)**	**(με)**	**(%)**
GERCC	GE151	1400	1059	341	24%
	GE252	1130	942	188	17%
	GE253	1150	884	266	23%
Conventional Concrete	CVC101	730	383	347	48%
	CVC102	790			
	CVC201	690	480	210	30%
	CVC302	650	591	59	9%
Core Samples*	CTR_1915	486			
	CTR_1998	531			
Average				**235**	**25%**

* Samples soaked then oven dried at 65°C to constant mass

For all trials, the extended curing period significantly reduced the drying shrinkage. On average the drying shrinkage was reduced by 25%. The findings are similar to the results presented in a recent ICOLD bulletin [4], which show shrinkage of specimens cured for 90 days to be 17% less than those cured for 28 days. This testing was done using slightly larger 100mm square by 285mm long specimens to ASTM C 157.

The shrinkage results obtained in the laboratory are much higher than expected in the dam, where extended water curing (56 day minimum) was specified. Furthermore, the drying environment following construction is less severe than in the laboratory test, given that the concrete is in a relatively moist environment.

5.2.1. WEATHERING

Other GERCC trials using site aggregates with a range of weathering were also undertaken. For these trials the water content was adjusted to provide consistent workability (vebe times) and all other parameters were kept the same. The "weathered" aggregate produced GERCC with drying shrinkage of approximately 1.5 times that of fresh aggregate. This confirmed the significance weathering has on the performance of the manufactured sand.

As part of these trials, some aggregate was produced using a largely weathered aggregate source, but it was pre-screened prior to crushing and a small scalp was taken from the crushing circuit to remove the material that was readily breaking down. This process was found to be very effective in limiting the shrinkage. The shrinkage of these samples was only approximately 5% more than the fresh aggregate.

5.2.2. MORTAR TRIALS

Mortar trials were undertaken to investigate the influence of the site-manufactured sand on shrinkage. A range of different site-manufactured sands (produced from fresh to weathered rock) were tested alongside an imported natural sand. The gradings were manufactured in the laboratory to be as similar as possible. The cementitious content was 380kg/m3, with 65% cement replacement with flyash. A water cement ratio of 0.72 was used for all mixes.

The results showed that the site manufactured sand (2,200 microstrian for fresh aggregate and up to 2,600 for weathered) exhibits considerably more drying shrinkage than imported natural sand (1,000 microstrain). The sand is therefore likely to be main cause of the high drying shrinkage of the GERCC. The results further highlight the significance weathering has on shrinkage.

5.3. CYCLIC WET/DRY TESTING

There was a concern that the GERCC may crack or deteriorate on exposure to repeated wetting and drying on account of the high drying shrinkage and the dimensional instability of the aggregate. To investigate this, the following tests were undertaken.

5.3.1. CUSTOMISED TEST 1

A new test method was developed which involves a daily cycle whereby the test specimens are soaked for six hours, dried at 65℃ for 15 hours, then cooled for three hours prior to length and dynamic modulus testing (such as is used in ASTM C666). Key observations from the testing are as follows:

- The length and dynamic modulus after seven cycles was more than the readings taken after the initial thorough drying cycle. This suggests that the cycle times are too short to enable complete drying (and possibly saturation) of the samples. If the test method is to be repeated, consideration could be given to extending the duration of the wetting and drying cycles.

- The dynamic modulus results did however indicate that the samples are not cracking or deteriorating quickly from repeated cycles of wetting and drying. The samples were subject to 70 cycles and the rate of decline in relative dynamic modulus was similar for the CVC and GERCC.

- The length measurements were also fairly consistent (following the initial measurement after seven cycles of wetting and drying), which indicates that the expansion and contraction seen by the samples on wetting and drying, is elastic.

- No definitive trends to distinguish the performance of the GERCC from the CVC were found.

5.3.2. CUSTOMISED TEST 2

Further cyclic wet/dry testing was undertaken to the following method:

Test specimens which had undergone the standard drying shrinkage testing (to AS1012.13) were used, (i.e. specimens were initially water cured for a week, then subject to 56 days of drying in a 50% humidity room). The specimens were then dried completely in an oven at 65℃. The specimens were cooled to 23 degrees, before measuring their length. The specimens were soaked until constant mass and then measured again. This drying and wetting cycle was repeated for five cycles.

Results of this testing from trials GE151, GE252 and CVC101 are presented in Figure 2. The results are similar for all trials in that approximately half of the initial shrinkage is irreversible; the remainder is largely elastic, although the range of movement diminishes slightly with repeated cycles. This is consistent with similar testing that has been undertaken by others [4].

The range of movement for GE151 is quite large (approximately 800 microstrain between saturated and dry states). This is however only 45% of the ultimate shrinkage following initial drying, within the range of 40-70% that could be expected [4]. A similar reversible range of shrinkage (in percentage terms) was observed for the other mixes tested. The range of movement in the field will however be much less, on account of the aforementioned site factors (extended curing duration and the moist environment).

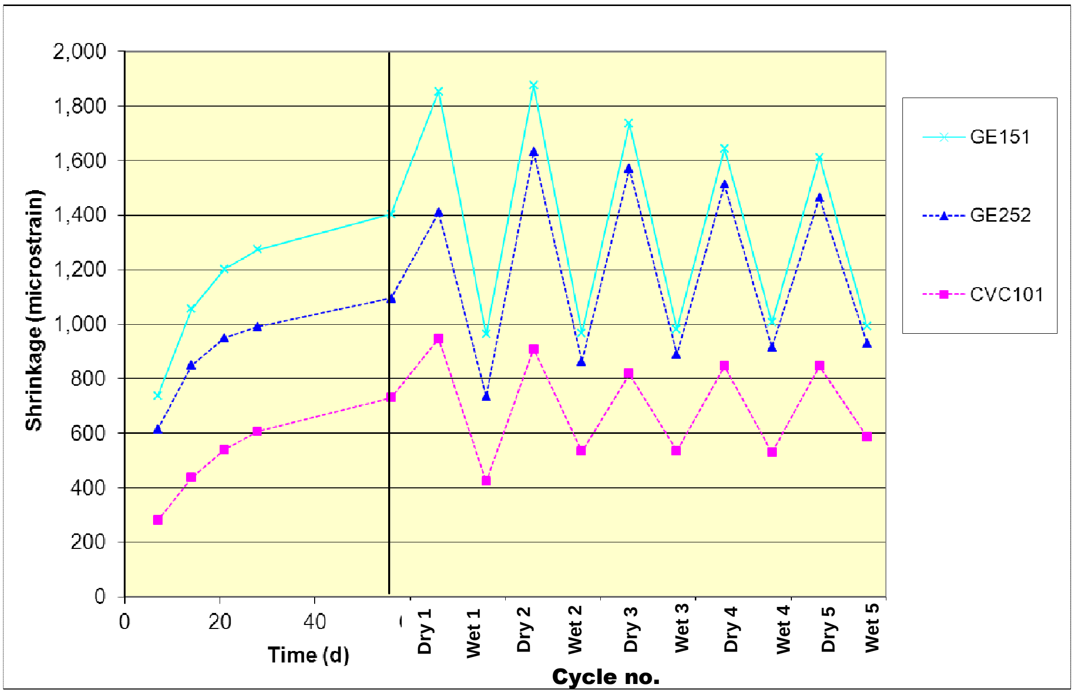

Fig. 2
Cyclic Wet/Dry Testing

5.4. ABRASION RESISTANCE

Testing was undertaken to investigate the abrasion resistance of the different mixes. Underwater abrasion resistance testing was undertaken to ASTM C1138M-05. A customised test involving an impacting jet of water was also undertaken. The test used a high-pressure industrial gurney with an oscillating head to impart a jet of water on the surface of completed test cylinders for an extended duration. Whilst the test was of some benefit, the jet caused fairly localised intense demolition, unlike the pattern or wear that could be expected on a stepped downstream face of a spillway. Improvements to the methodology could be made through the use of a low head, high volume jet, which would more closely replicate flood impact loading. More sophisticated equipment would however be required.

The GERCC was found to have similar abrasion resistance to the CVC mixes in both tests.

5.5. FREEZE THAW

Freeze thaw testing to ASTM C666, Procedure A, was undertaken to investigate the susceptibility of the GERCC to freeze thaw damage, without the benefit of any air entrainment (aside from GE253 which contained only minimal (2.5%) air). The test involves cycling the specimens (75 x 75 x 280mm prisms) submerged in water between 4C and -18C.

CVC302 passed the test and was found to be freeze thaw durable. All of the other mixes did not perform well in the test. The 1915 concrete, GE403 and GE402 did show some resistance, surviving approximately 55 to 30 cycles respectively (approximately 10% of the 300 they were to withstand to be deemed freeze-thaw durable). The other mixes displayed little if any resistance to the test.

The test was too severe to provide meaningful insight to the performance of the mixes in the local climate. The performance of the higher strength GERCC mixes was however somewhat superior to the non air entrained CVC mixes, and similar to that of the 1915 concrete which has performed well in the local climate over its 100 years of service. Around 5% air entrainment is required for concrete to be genuinely freeze thaw durable, although this varies depending on the maximum size aggregate and other factors [6].

5.6. MODULUS AND THERMAL EXPANSION

Elastic modulus and thermal expansion testing was undertaken for comparison with the RCC. If the facing mix is considerably different to the RCC, there is a risk of it cracking, within itself, or along the interface with the RCC.

The results of the testing are presented in Table 4. The GERCC mixes have a very similar modulus to the parent RCC, whereas the CVC is considerably stiffer. Similarly the coefficient of thermal expansion of the GERCC mixes is more similar to the parent RCC than the CVC mixes. In terms of both modulus and thermal expansion, the GERCC mixes are therefore preferred over CVC.

Table 4
Modulus and Thermal Expansion Test Results

Type	Name	25% Secant Modulus (GPa) 90d	Coefficient of Thermal Expansion (uE/deg C)
GERCC	GE151	22.4	9.7
	GE252	24.4	10.0
	GE253	24.6	9.7
Conventional Concrete	CVC101	32.4	10.9
	CVC201	34.8	11.1
	CVC302	31.5	11.4
RCC	Average	24.0	9.6

6. OUTCOME

The outcome of the testing program was that GERCC was adopted to serve as facing of the dam. The specification was customised by relaxing some criteria and introducing others (such as MBV testing) so that the intended performance characteristics will be achieved. Moderately weathered material was permitted for use although a prescriptive requirement regarding pre-screening was included in the specification, with details based on the findings of the trials.

6.1. FINAL GERCC MIX DESIGNS

Since the initial trials, the RCC mix design was refined. The final aggregate grading includes a slightly lower sand content and reduced rock fines content (minus 75um size). A high water reducer/retarder dosage was used (to produce initial set at approximately 18 hours). The cement content was reduced (to 75kg/m3) and the flyash content was increased (to 120kg/m3), resulting in a net increase in the volume of cementitious material.

The percentage of weathered and altered aggregate (particularly the rock fines portion) was controlled via pre-screening and scalping as per the specification. The abundance of altered material was also limited by selectively excluding the most highly altered material, for use in other applications. This was differentiated by colour. Through this process it was possible to limit the MBV of the sand to 6 or less.

The aforementioned changes contributed to a reduced water demand. The free water in the final RCC mix design is 105L/m3, approximately 12.5% less than in the initial trials (described in Section 4).

7. FIELD PERFORMANCE

From testing undertaken during construction, the drying shrinkage of the GERCC used in the facing of the dam has ranged from 700 (for the 25MPa GERCC used in the primary spillway) to 920 microstrain (for the 15MPa GERCC used elsewhere). This is considerably less than the results obtained during the initial trials (up to 1400 for GE151).

The partially built dam was overtopped during construction by a significant flood (estimated to be approximately 1 in 100AEP), which overtopped the dam for eleven days with a peak of approximately 2m over the crest. The GERCC steps endured very well. The only obvious surface deterioration was in places where it had been abraded by construction equipment (such scaffold tubing) dangling in the flow.

8. CONCLUSIONS

Geothermal alteration and weathering can change the mineralogy of the rock such that its performance characteristics in concrete are significantly affected. An intensive campaign of trials and testing enabled a customised specification to be prepared, specific for the projects needs. This enabled GERCC facing of the dam using site won aggregates to be adopted, and significant savings to be made.

The knowledge gained through the trials meant that a process could be developed to utilise rock that might otherwise have been spoiled, (e.g. rock from abutment excavations and the upper (moderately weathered) profile of the quarry), without compromising quality. Similarly, it enabled the material from the dam foundation excavation to be used, which ended up a significant portion of the total aggregate produced (approximately 25%). This presented a significant saving to the project.

The trials enabled the development of simple guidelines to assist in selection of rock for crushing. Furthermore the simple aggregate testing program adopted (including frequent MBV tests) meant that produced materials could be promptly evaluated, knowing with some certainty, that if the criteria is satisfied, suitable performance characteristics would be achieved.

Heavily retarding the RCC with a water reducer/retarder provided not only construction flexibility (in terms of extended set times, allowing more hot and warm joints to be achieved) but also enabled the water content to be significantly reduced. In turn, this improved the strength and drying shrinkage properties of the GERCC.

A high rock fines (<75um) content can be beneficial in RCC mix design as it can reduce the amount of cementitious material that may otherwise be needed as a filler (ref). On this occasion however, the mineralogy of the weathered and altered material present in the source rock was such that the rock fines significantly affected water demand and shrinkage. As a result, the rock fines content had to be limited so as to meet the required performance characteristics of the GERCC facing.

REFERENCES

[1] Cement Concrete and Aggregates Australia, *"Guide To The Specification And Use Of Manufactured Sand In Concrete"*. CCAA T60, 2008.

[2] Concrete Institute of Australia, *"A Guide To NSW Concrete Aggregates And Their Influence On Shrinkage And Creep"*. Sydney, 1981.

[3] Fujiwara, T. "Effect of Aggregate on Drying Shrinkage of Concrete". Journal of Advanced Concrete Technology, Vol. 6, No. 1, pp31-44. Japan Concrete Institute, 2008.

[4] International Commission on Large Dams, "The Physical Properties of Hardened Conventional Concrete in Dams". ICOLD Bulletin 145, 2009.

[5] International Slurry Surfacing Association, *"Test Method For Determination of Methylene Blue Value (MBV) of Mineral Aggregate Fillers and Fines"*. Technical Bulletin No. 145, 1989.

[6] Neville, A.M. *"Properties of Concrete". Fourth Edition, Pearson Education Limited, England, 1995.*

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