Concrete Beton, Volume 104, pp 11-13, August 2003

Quality of Western Cape Sandstone as Concrete Aggregate

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A comparative assessment of the quality of sandstone properties was made by comparing the results with those achieved by concrete containing either granite or greywacke aggregate. Sandstone aggregates were found to have lower strength and stiffness than traditional coarse aggregates and may produce concrete of lower elastic modulus and higher drying shrinkage capacity.

Despite these drawbacks, the sandstone aggregate can be used for most structural applications provided some allowance is made for its effect on hardened concrete properties.

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TECHNICAL PAPER

QUALITY OF WESTERN CAPE SANDSTONE AS CONCRETE AGGREGATE

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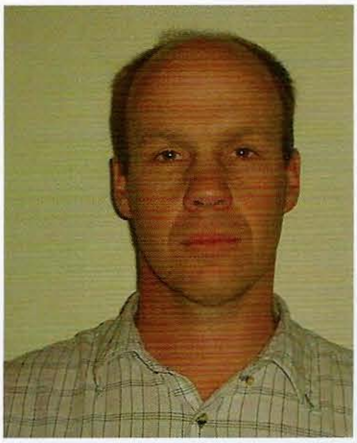

James Mackechnie is a graduate of the University of Cape Town where he spent the last eight years researching concrete materials. Research involved cement replacement materials, marine concretes and durability of concrete structures. James is currently working for the Cement and Concrete Association of New Zealand based at the University of Canterbury. Current research includes studying New Zealand concrete aggregates and developing new cementitious systems.

ABSTRACT

Sandstone coarse aggregate is currently being used extensively in the Western Cape for concrete construction. There is however little performance data on the material, particularly with regard to its effect on hardened properties of concrete. Four local sandstone aggregate types, that are being used commercially, were selected and tested for a range of aggregate and concrete properties. A comparative assessment of the quality of sandstone properties was made by comparing the results with those achieved by concrete containing either granite or greywacke aggregate. Sandstone aggregates were found to have lower strength and stiffness than traditional coarse aggregates and may produce concrete of lower elastic modulus and higher drying shrinkage capacity. Despite these drawbacks, sandstone aggregate can be used for most structural applications provided some allowance is made for its effects on hardened concrete properties.

INTRODUCTION

The Table Mountain Series consists principally of sandstone material and extends from Cape Town to the Eastern Cape[1]. Sandstone is a common sedimentary rock produced by the accumulation of quartz grains cemented with a variety of minerals under high pressure from superincumbent loads. High levels of compaction and cementation cause a physical transition of the rock to harder stages described as quartzitic sandstone or quartzite[2]. Generally it is accepted that sandstone aggregates are relatively weak and friable with improving properties as the metamorphic transition proceeds towards quartzite.

The use of sandstone aggregate appears to be growing in the Western Cape in competition with traditional concrete stone sources from granite and greywacke. Sandstone deposits are widespread throughout the Table Mountain formation and the aggregate can be produced cost-effectively. Most South African aggregates used in concrete are well documented with detailed performance data[3]. There is some concern about the lack of performance data on sandstone aggregates, specifically with regard to issues such as strength, dimensional stability and durability. Sandstone aggregates of the Karroo System were in fact considered of doubtful suitability for use in concrete from research done in 1960 by Roper[4].

AGGREGATE TESTING

Four sources of sandstone aggregate were used for testing along with samples of granite and greywacke stone. Details of the aggregates and the location of the materials are given in Table 1. Large uncrushed samples were taken from quarries for aggregate testing together with crushed 19 mm stone. It should be noted that only a limited number of samples were selected which might not be truly representative of material being produced at the quarries. This was particularly problematic at river and pit quarries that crushed rock ranging from fairly friable soft sandstone to harder more quartzitic material.

Cored and crushed stone was tested for porosity, unconfined compressive strength, 10% FACT and static elastic modulus. Testing of the stone was done for comparative purposes using standard testing procedures. Results of the aggregate testing are shown in Table 2.

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Table 1: Details of course aggregate material

Name	Location	Geological type and source
GN	Malmesbury	Crushed granite - Rheebok quarry
GW	Durbanville	Crushed greywacke - Peninsula quarry
SSA	Overberg	Crushed quartzitic sandstone - hardrock quarry
SSB	Worcester	Moelenaars River - dredged sandstone boulders
SSC	Paarl	Berg River – excavated sandstone boulders
SSD	Paarl	Berg River – excavated sandstone boulders

Table 2: Aggregate test results

Stone Type	Absorption %	UCS (MPa)	10% (kN)	Elastic moduls (GPa)
GR	0.27	235-303*	254	68-76*
GW	0.18	297-308*	418	68-77*
SSA	0.82	129-150	117	24-25
SSB	0.38	212-233	143	22-23
SSC	3.80	95-130	111	8-14
SSD	2.45	130-235	123	54-75

* results by Davis and Alexander[5]

a) Absorption
Water absorption of different rock types was measured by vacuum saturating thin slices (5-10 mm thick) of the material in water. Sandstone aggregate was found to have higher levels of absorption compared to granite and greywacke, indicating a more porous microstructure. Sandstone from the Berg River areas was found to have extremely high absorption being well over 2%.

b) Unconfined compressive strength (UCS)
Cores of 68 mm diameter were extracted from large sandstone blocks and boulders. The core samples were cut and ground plane and parallel such that an equal height to diameter was achieved. The cores were then tested for unconfined compressive strength (UCS) by recording to ultimate crushing value in compression. The UCS of sandstone was fairly variable but was generally below the reported values for granite and greywacke aggregate. The Moelenaars River sandstone was found to have consistently high strengths of over 200 MPa.

c) 10% FACT
Testing for 10% FACT was conducted in accordance with SABS 842 using dry crushed aggregate[6]. The test measures the resistance of aggregate to pulverization and is considered to be a reasonable estimate of crushed stone quality. Sandstone had moderate resistance to pulverization with a maximum value of 143 kN for the Moelenaar river material and only 111 kN for the Berg River aggregate. Granite and greywacke had considerably higher 10% FACT values being 254 and 418 kN respectively.

d) Elastic modulus
Static elastic modulus testing was done on 100 mm diameter core samples using electronic stress-strain measurements. Testing consisted of a gauge length of 100 mm within a circular clamping device with a linear voltage displacement transducer connected to an automatic recorder.

Apart from SSD, all sandstone samples had consistently low elastic moduli of less than 26 GPa. Greywacke and granite typically have elastic modulus values greater than 70 GPa. The variability of results was partly due to the limited amount of sampling done on each source (limited to three boulders from each quarry). River boulders in particular where found to vary considerably in quality, as they come from different geological areas and being exposed to varying amounts of weathering.

Whilst it is acknowledged that some of the softer material might be removed during crushing and grading it was apparent when inspecting crushed aggregate stockpiles at the Berg River quarries that some softer material remained. Some of this sandstone aggregate was so friable that it was possible to crush the material between thumb and forefinger.

CONCRETE TESTING

Crushed 19 mm aggregate was used together with CEM I cement and Cape Flats dune sand to produce a grade 35 concrete. Details of the concrete mix design are given in Table 3.

Table 3: Concrete mix design (kg per cubic metre of concrete)

Material	Grade 35	Actual slump
Cement	333	35 - 75 mm
Water	200	
19mm stone	1100	
Dune sand	787	
Plasticizer	0	
Target slump	50 mm	

Concrete was mixed for three minutes in a rotary pan mixer before being cast and compacted in 100 mm cube moulds and 100x100x200 mm prisms moulds. Demoulding of the concrete specimens was done after 24 hours and concrete was cured in water at 23°C. After 14 days concrete prisms were removed from curing tanks and exposed to a controlled drying environment to assess the drying shrinkage potential of the material. Compressive strength and elastic modulus were tested at 28 days in accordance with standard methods[7]. Details of concrete tests results are summarized in Table 4.

a) Compressive strength
Compressive strength results were found to fall in the expected range between 36 and 41 MPa. Whilst concrete containing sandstone coarse aggregate was generally lower than concrete containing granite or greywacke, the differences were not particularly significant.

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Furthermore the effect of stone quality on compressive strength is usually only noticeable on high strength materials (i.e. cube strengths above 50 MPa)[8].

Table 4: Concrete test results at 28 days

Stone type	Compressive strength (MPa)	Elastic modulus (GPa)	Shrinkage at 28 days (microstrain)
GR	41.0	30.1	242
GW	39.3	29.0	180
SSA	39.9	22.4	358
SSB	38.2	21.7	307
SSC	35.5	20.5	320
SSD	35.8	20.9	295

b) Elastic modulus

Static elastic modulus testing was done using electronic strain measurements on concrete prisms in the same manner as that used to test rock cores. Concrete made with sandstone coarse aggregate showed elastic modulus values consistently below 23 GPa at 28 days. In comparison, concrete containing granite or greywacke had elastic moduli of approximately 30 GPa. The lower stiffness of sandstone therefore appeared to be responsible for the 25% loss in performance of elastic modulus of concrete made with sandstone aggregate.

Similar results have been found when site concrete containing sandstone was tested (grade 25 MPa concrete using SSA aggregate had a measured elastic modulus of 18.7 GPa at 28 days)[9].

c) Drying shrinkage

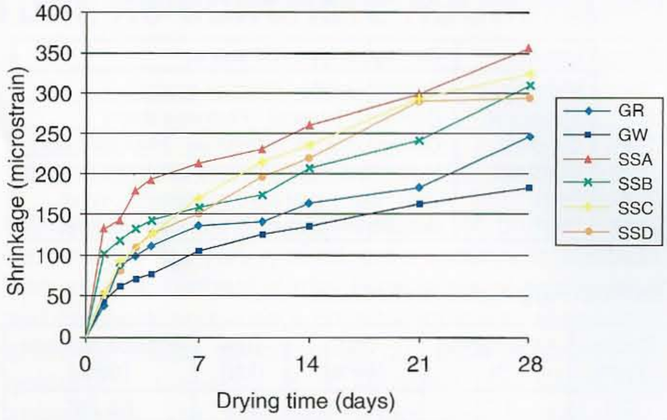
Drying shrinkage was measured on actual concrete specimens of reasonable size (100x100x200 mm prisms) in order to obtain realistic comparisons. Testing was done in accordance with SABS method 1085 where concrete specimens are exposed to a controlled environment of 23 0C and 60% R.H.[10]. Drying shrinkage was only measured over a period of 28 days to get a comparative assessment of shrinkage potential for each concrete type.

Shrinkage measurements during the 28 days of drying are shown in Figure 1. A total of six shrinkage measurements were made for each concrete type with statistical outliers being eliminated (maximum of one set of readings per concrete type). Concrete containing sandstone coarse aggregate had consistently higher rates of drying shrinkage (approximately 50% higher) than concrete made with granite or greywacke.

CONCLUSIONS

Results from this limited investigation suggest that sandstone quality is quite variable even within localized areas. Overberg and Worcester sandstone appeared to perform slightly better than the Paarl material when comparing aggregate test results and elastic modulus values. All four sandstone types did however produce significantly higher levels of drying shrinkage than would be expected from structural concrete.

Figure 1: Drying shrinkage measurements (microstrain)



Sandstone from the Table Mountain Series can be used to produce structural concrete within the normal range. The use of such material makes good economic sense given the limitations of traditional stone sources in the area. Indeed the material has been used extensively in the Western Cape in recent years without major problems.

Care should however be taken when using the material in structures sensitive to deflections, long-term deformations or drying shrinkage. Sandstone aggregate tends to produce concrete of lower elastic modulus and higher shrinkage capacity than traditional concrete made with granite or greywacke aggregate. In sensitive structures some allowance needs to be made when using concrete made with sandstone aggregate to ensure satisfactory performance.

ACKNOWLEDGEMENTS

Laboratory testing reported in this paper was largely undertaken by the following students at the University of Cape Town during 1999 and 2000; Hassen Jaufeerally, Chia-Wen Hsu and Nadia Ebrahiem.

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