The Magazine Of
The Institution Of Engineers, Singapore
April 2016 MCI (P) 002/03/2016

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THE SINGAPORE ENGINEER

COVER STORY:

CIVIL & STRUCTURAL ENGINEERING

368 Thomson

FEATURES:

• Road Pavement Technology • Concrete Technology • Aerospace Engineering

Use of sedimentary rocks in road construction in Singapore

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In Singapore, about 3.7 million m^3 of sedimentary rocks have been excavated from the Jurong Rock Caverns project. Due to limited landfill space, this poses potential storage problems. Hence, there is a need to use the rock for beneficial applications. This article describes a study that was carried out on the use of sedimentary rocks in asphaltic concrete for road construction. The study was conducted with respect to the asphalt wearing course and binder course. The results of laboratory tests showed that with some modification, the asphaltic concrete containing sedimentary rocks can provide a performance that is comparable to that of conventional asphaltic concrete containing granite.

INTRODUCTION

In Singapore, an estimated 3.7 million m^3 (equivalent to 6.2 million tons) of sedimentary rocks have been excavated from the Jurong Rock Caverns project. More sedimentary rocks are anticipated to be generated in the future, with the increased interest in exploration of underground developments within the Jurong Formation area. At present, most of these rocks are being stockpiled in Jurong Island and this poses potential storage problems. Hence, there is a need to use the rocks for beneficial applications. A study, which was partially funded by JTC Corporation and the Singapore Government Public-Private Co-Innovation Partnership (CI Partnership) Program, was carried out to investigate the use of sedimentary rocks in asphaltic concrete for road construction. The study was conducted with reference to the wearing course and binder course specifications of Singapore's Land Transport Authority (LTA). The study was conducted in two phases. In Phase 1, the rocks were collected from Jurong Rock Caverns and delivered to a processing plant for processing into aggregates. The properties of the aggregates were determined and compared to LTA requirements.

In Phase 2, laboratory tests were conducted to evaluate the use of sedimentary aggregates in asphaltic concrete. The mix design was determined for the asphaltic concrete containing 100% sedimentary aggregates. Performance properties were evaluated to compare the performance of asphaltic concrete containing sedimentary aggregates versus asphaltic concrete containing granite which is typically used in Singapore. The tests included the indirect tensile strength test, moisture sensitivity test, dynamic creep test and rutting resistance test.

PROCESSING OF SEDIMENTARY ROCKS

As compared to granite (which is a type of igneous rock), sedimentary rocks are formed in layers and thus, the crushed sedimentary rocks are prone to being more flaky and elongated as compared to crushed granite rocks. The processing of the sedimentary rocks was carried out using a crushing process configuration shown in Figure 1. The process configuration maximises aggregate quality by feeding the material through two stages of crushing, and the feed gradation is optimised to

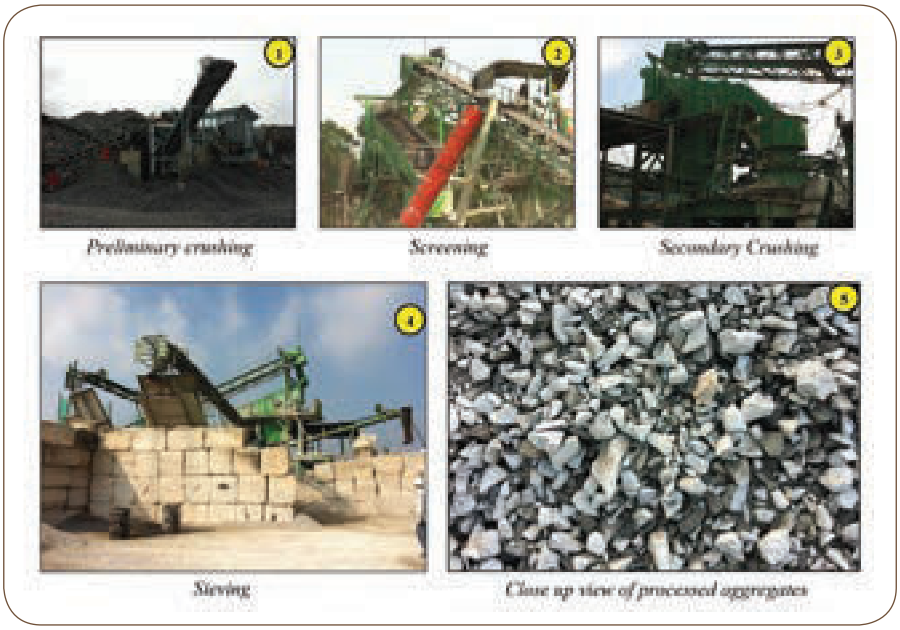

Figure 1: Processing of sedimentary rocks

the secondary crusher so that it can produce better aggregate shapes. The processing of the sedimentary rocks involved a few key stages, described as follows:

- Preliminary crushing: Rocks were crushed on-site into particle sizes smaller than 300 mm, via a jaw crusher.
- Screening: Crushed rocks were screened to remove aggregate sizes which are bigger than 19 mm.
- Further crushing: Rocks retained on the 19 mm sieve were fed into a cone crusher to breakdown the aggregates into smaller sizes.
- Stockpiling processed aggregates: The three different sizes of processed aggregates, ranging from 19 mm - 14 mm, 14 mm - 5 mm, and 5 mm and below, were stockpiled and samples of the aggregates were collected and tested for properties including gradation, flakiness index and elongation index.

AGGREGATE PROPERTIES

Petrographic analysis showed that sedimentary rock from the Jurong Rock Caverns project is mainly siltstone. The processed sedimentary aggregates were tested according to the LTA specifications. The three sizes of processed sedimentary aggregates were sent to independent testing laboratories for testing. The test results are shown in Tables 1 and 2.

All the test results met the LTA requirements.

MARSHALL MIX DESIGN

One hundred percent sedimentary aggregates were used for both the W3B wearing course and B1 binder course to maximise the usage of sedimentary aggregates. A series of test samples were prepared for W3B and B1 asphaltic concrete mixes containing sedimentary aggregates, as shown in Table 3. Each series comprises five sets of test samples with different bitumen con-

Properties	19-14 mm	14-5 mm	LTA Requirements
Particle density (oven dry)	2.72 Mg/m^3	2.73 Mg/m^3	Nil. Granite is about 2.6 to 2.7
Water absorption	0.4%	0.4%	Max 1%(1)
Los Angeles abrasion	12%	12%	Max 35%(1)
Flakiness index	20%	24%	Max 35%(1)
Elongation index	28%	33%	Max 35%(1)
Impact value	N.A	5%	Max 30%(1)
Crushing value	N.A	15%	Max 25%(1)
Percent fractured faces (at least 2 faces)	75%	81%	Min 75%(2)
Soundess loss by magnesium sulfate	1%	1%	Max 12%(2)
Silt content of raw aggregate	0.5%	1.4%	Max 2%(1)
Polished stone value	N.A	53	Nil. Granite is about 50 to 55

1) According to LTA Code of Practice for Works on Public Streets (10 Mar 2009)

2) According to LTA Materials and Workmanship Specifications for Civil & Structural Works (June 2010)

Table 1: Test properties of coarse aggregates

Properties	5mm and below	LTA Requirements
Los Angeles abrasion	24%	Max 35%(1)
Soundess loss by magnesium sulfate	2%	Max 12%(2)
Silt content	0.3%	Max 0.3%(2)
Liquid limit	24%	Max 25%(2)
Plasticity index	N.A	Max 6%(2)

1) According to LTA Code of Practice for Works on Public Streets (10 Mar 2009)

2) According to LTA Materials and Workmanship Specifications for Civil & Structural Works (June 2010)

Table 2: Test properties of fine aggregates

tents, ranging from 4.0% to 6.0% of the total mass of asphaltic concrete, at 5% intervals. Each set of test sample consisted of three replicates. The Marshall mix design was carried out according to ASTM D1559-89 and Asphalt Institute Manual Series No 2 (Asphalt Institute, 1997).

Determination of design bitumen content

The design bitumen content of the asphaltic concrete mixes was selected at the median of the required percentage of air voids (ie 3% to 5%) which is 4.0%, according to recommendations by the Asphalt Institute (1997). The corresponding mix design properties at the respective design bitumen content were evaluated, as shown in Table 4.

Initial assessment

Initial tests were carried out for W3B and B1, using 100% sedimentary aggregates to replace granite aggregates. The moisture sensitivity test was conducted according to BS EN 12697-12: 2007, to evaluate the effect of water on the indirect tensile strength of the asphaltic concrete. The tensile strength ratio (TSR) result for W3B-100% sedimentary aggregates was 57.2% and for B1-100% sedimentary aggregates was 60.5%. TSR results were found to be poor as both results were less than the typical value of 70%-80%. These results indicated that W3B and B1 mixes with sedimentary aggregates have a high potential for moisture-induced damage.

Anti-stripping agent

The primary goal of an anti-stripping agent is to improve the moisture sensitivity of the asphalt mixture, through improving the bond between the asphalt binder and the aggregate. A commercially available anti-stripping agent (Gripper 4131) was used in this study. In order to achieve a higher success rate in predicting moisture susceptibility in asphaltic concrete, the recommendation was to adopt a TSR of 80% (Kiggundu and Roberts, 1988). A preliminary study was carried out to verify the optimal anti-stripping agent content to be used. Five binder samples were prepared, at various anti-stripping agent contents, namely, 0%, 0.1%, 0.3%, 0.5% and 0.7% by mass of binder. The samples were then used for the preparation of W3B and B1 asphaltic concrete containing 100% sedimentary aggregates based on their design bitumen contents at 4.9% and 4.7%, respectively. The verification was carried out based on the moisture sensitivity test which was conducted according to ASTM D4867-04, as shown in Tables 5 and 6.

Mix Classification		Road Mixes			
Type of Mix		W3B Wearing Course		B1 Binder Course	
Thickness of Course		40 - 65 mm		50 - 100 mm	
Max Size of Stone		19 mm		35 mm	
(BS) Passing	50 mm	-		-	
	37.5 mm	-		100	
	25 mm	-		95 - 100	
	19 mm	100		84 - 92	
	13.2 mm	85 - 95		65 - 82	
	9.5 mm	-		-	
	6.3 mm	58 - 68		48 - 62	
	3.35 mm	40 - 50		35 - 50	
	1.18 mm	21 - 31		22 - 35	
	300 µm	11 - 17		12 - 19	
	75 µm	4 - 8		3 - 8	
% Soluble Bituman (60/70 Penetration Grade) (% by Weight of Total Mix)		Min	Max	Min	Max
		4.5	5.5	4.5	5.5

Table 3: Mix specification (LTA, 2010)

Mix Properties	W3B - 100% Sedimentary Aggregates	B1- 100% Sedimentary Aggregates	LTA Requirement (Table 10.8, LTA, 2010)
Design bitumen content (%)	4.9	4.7	4.5 – 5.5
Bulk density (Mg/m^3)	2.40	2.43	Nil
Stability (kN)	11.3	10.9	Minimum 9
Flow (mm)	3.8	3.8	2 – 4
Voids content (%)	4.0	4.0	3 – 5
Voids filled with bitumen (%)	76	75	75 – 82

Table 4: Mix design properties at the design bitumen content

Anti-stripping agent content (by mass of binder)	Wet ITS (kPa)	Dry ITS (kPa)	TSR
0%	319.2	718.9	44.4%
0.1%	689.5	891.3	77.4%
0.3%	749.6	800.8	93.6%
0.5%	855.6	969.9	88.2%
0.7%	967.1	979.3	98.8%

Table 5: Effect of anti-stripping agent content on the moisture sensitivity test results for W3B containing 100% sedimentary aggregates

Anti-stripping agent content (by mass of binder)	Wet ITS (kPa)	Dry ITS (kPa)	TSR
0%	489.9	787.2	62.2%
0.1%	881.8	1022.8	86.2%
0.3%	910.2	1092.2	83.3%
0.5%	981.5	1083.5	90.6%
0.7%	954.6	1134.5	84.1%

Table 6: Effect of anti-stripping agent content on the moisture sensitivity test results for B1 containing 100% sedimentary aggregates

Except for W3B with 0.1% anti-stripping agent, most of the TSR results were above 80%. Therefore, the most optimal content of anti-stripping agent recommended to be used is 0.3% as it can achieve a TSR of at least 80% and save cost since it is evident that using more anti-stripping agent to increase TSR will incur higher cost.

Verification of mix design properties at design bitumen content

Based on 0.3% anti-stripping agent dosage, Marshall mix design parameters for W3B and B1 containing 100% sedimentary aggregates were evaluated. The results, as shown in Table 7, indicate that all the mix design properties are within the LTA requirements.

Mix Properties	W3B - 100% Sedimentary Aggregates + 0.3% Gripper 4131	B1- 100% Sedimentary Aggregates + 0.3% Gripper 4131	LTA Requirement (LTA, 2010)
Design bitumen content (%)	4.9	4.7	4.5 – 5.5
Bulk density (Mg/m^3)	2.40	2.43	Nil
Stability (kN)	10.7	10.7	Minimum 9
Flow (mm)	3.4	3.5	2 – 4
Voids content (%)	3.9	3.7	3 – 5
Voids filled with bitumen (%)	75.5	75.2	75 – 82

Table 7:Verification of mix design properties at design bitumen content

Test	Standard/ Method	Test Temperature	Test Objective
Rutting resistance	BS EN 12697-22: 2003	45˚C	Wheel-tracking rate Rut depth
Moisture sensitivity	BS EN 12697-12: 2007	25˚C Wet Conditioning: 40˚C	Tensile Strength Ratio
Indirect tensile strength	BS EN 12697-23: 2003	25˚C	Indirect tensile strength
Dynamic creep	BS EN 12697-25: 2005	40˚C	Dynamic creep modulus
Maximum density	BS EN 12697-5: 2009	25˚C	Maximum density G_{mm}

Table 8:Test methods used for asphaltic concrete testing

PERFORMANCE TESTS

Performance tests were conducted on the W3B and B1 containing 100% sedimentary aggregates and 0.3% anti-stripping agent as well as on W3B and B1 containing 100% granite aggregates, for comparison. These tests included rutting resistance test, moisture sensitivity test, indirect tensile strength test, dynamic creep test and maximum density test, as shown in Table 8 and Figures 2 to 5.

Test results summary

The tests results are summarised as shown in Tables 9 and 10. The results showed that most of the test properties of the asphaltic concrete containing sedimentary aggregates (and Gripper 4131 anti-stripping agent) are comparable to those of asphaltic concrete containing granite aggregates.

CONCLUSIONS

This article describes the work that was carried out to evaluate the use of sedimentary rocks in asphaltic concrete for road construction. Excavated sedimentary rocks obtained from Jurong Rock Caverns were processed and analysed. As compared to granite rocks, sedimentary rocks are more flaky and elongated when they are crushed, due to their layered characteristics. Hence a two-stage crushing process that maximises the aggregate quality

Properties	Test method	W3B- 100% Granite (control)	W3B- 100% Sedimentary aggregates + 0.3% Gripper	Significance test using Student's t-test at 5% level
Wheel-tracking rut depth	BS EN 12697-22: 2003	1.8 mm	1.8 mm	No significant difference
Wheel-tracking rate	BS EN 12697-22: 2003	0.31 micron/cycle	0.30 micron/cycle	No significant difference
Moisture sensitivity test – tensile strength ratio	BS EN 12697-12: 2007	89.4%	95.0%	–
Indirect Tensile strength	BS EN 12697-23: 2003	1.15 MPa	1.12 MPa	No significant difference
Dynamic creep modulus	BS EN 12697-25: 2005	4.7 MPa	4.5 MPa	No significant difference
Maximum density	BS EN 12697-5: 2009	2.45 Mg/m^3	2.50 Mg/m^3	Significant difference

Table 9. Asphaltic concrete tests on W3B

Properties	Test method	B1-100% Granite (control)	B1-100% Sedimentary aggregates + 0.3% Gripper	Significance test using Student's t-test at 5% level
Wheel-tracking rut depth	BS EN 12697-22: 2003	1.5 mm	1.0 mm	Significant difference
Wheel-tracking rate	BS EN 12697-22: 2003	0.27 micron/cycle	0.20 micron/cycle	Significant difference
Moisture sensitivity test – tensile strength ratio	BS EN 12697-12: 2007	93.4%	95.5%	–
Indirect Tensile strength	BS EN 12697-23: 2003	1.25 MPa	1.26 MPa	No significant difference
Dynamic creep modulus	BS EN 12697-25: 2005	8.3 MPa	9.1 MPa	No significant difference
Maximum density	BS EN 12697-5: 2009	2.46 Mg/m^3	2.55 Mg/m^3	Significant difference

Table 10. Asphaltic concrete tests on B1

Figure 2: Wheel tracking machine (left) and close-up view of test sample (right)

Figure 3: Universal testing machine (left) and dynamic creep test (right)

Figure 4: Indirect tensile strength test

Figure 5: Uncompacted sample for G_{mm} measurement (left) and sample placed in a pyknometer (right)

(ie cubical shape) was employed. In addition, the crusher operating parameters were also optimised in order to produce cubical aggregate shapes. The aggregate test results showed that all the coarse and fine sedimentary aggregates met the LTA specification requirements for W3B and B1 asphaltic concrete. Hence, it was proposed that 100% of the processed sedimentary aggregates be used in the asphaltic concrete study.

A laboratory study was carried out to evaluate the use of sedimentary aggregates in two types of asphaltic concrete mixes, namely, W3B and B1. In Phase 1, the mix design of each type of asphaltic concrete was determined using the Marshall design method according to the LTA specification requirements. The design bitumen contents were determined for W3B and B1 at 4.9% and 4.7%, respectively, which are quite similar to that for conventional W3B and B1 containing granite aggregates.

Asphaltic concrete tests were carried out to determine the performance of the asphaltic concrete in comparison with that of asphaltic concrete containing granite aggregates.

Preliminary tests revealed that the asphaltic concrete containing sedimentary aggregates showed poor resistance to moisture, based on the moisture sensitivity test. Modification was carried out on the asphaltic concrete using a type of anti-stripping agent to improve its moisture resistance. Further asphaltic concrete tests were then carried out on W3B and B1 containing sedimentary aggregates and anti-stripping agent. A study was conducted to determine the optimal anti-stripping agent content to be used. The results showed that the optimal content was at 0.3% (by mass of binder). This was used for subsequent performance tests which included the rutting resistance test, moisture sensitivity test, indirect tensile strength test, dynamic creep test and maximum density test. The results showed that most of the test properties of the asphaltic concrete containing sedimentary aggregates (and anti-stripping agent) are comparable to those of asphaltic concrete containing granite aggregates. To-date, a field trial has been conducted on the asphaltic concrete containing sedimentary rock and its performance is still being monitored. The success of this project could lead to a significant contribution to the sustainable development of Singapore, as the sedimentary rocks can provide an alternative to granite aggregates for road construction.

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[This article is based on a paper authored by Ho Nyok Yong, Lee Yang Pin Kelvin and Moe Aung Lwin, Samwoh Corporation Pte Ltd, and Leong Pei Ying Cherlyn and Zhang Weide, JTC Corporation, and presented at the 33rd Conference of the ASEAN Federation of Engineering Organisations (CAFEO 33) which was held in Penang, Malaysia, from 22 to 26 November 2015].