MIX DESIGN OF CORAL AGGREGATE CONCRETE

REPORT FOR BLIGH TANNER

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Background

Coral aggregates are used to make concrete in the islandic countries for their abundant availability as compared to conventional aggregates. However, the research in the properties of coral aggregate concrete including strength, durability and mix design is still very limited. Builders in the small islands of Oceania such as in Vanuatu and Palau use the mix proportions for coral aggregate concrete based on their experience as the properties of coral sand and gravel and their effects on the concrete are not well known. Hence, development of proper mix design for coral aggregate concrete is of paramount importance.

With the view mentioned above, Bligh Tanner desires a mix design of coral concrete for their ongoing projects in Vanuatu specifically for suspended slabs for the ultimate design strength of 25MPa. To conduct this mix design, they provided a small sample of coral sand and gravel to test their properties (grading, densities) that are required for the mix design computation. In addition, two (2) coral concrete cylinders which were mixed and poured on the site in Vanuatu as per builder's mix proportion of cement 1: sand 1: gravel 2 with water cement ratio of 0.5 were delivered for testing in QUT lab to ascertain the failure mode and the strength. The average strength of cylinders was determined as 27.6 MPa. Based on the available data and the test results, a mix design for coral concrete to achieve the strength of 25 MPa has been developed and is reported in this document.

Key Literature Findings

Available research in the field of coral concrete is still very preliminary. Most of the research has been conducted by Chinese researchers for the corals used in concrete in reclamation projects for Chinese islands. The key research findings can be summarised as below:

- Coral aggregates have rough surface and porous structure and these features seriously affect the workability, mechanical property, failure mode and durability of coral concrete. Additionally, because of these features, the common concrete mix design is not always feasible/suitable for coral aggregate concrete (Wang et al, 2018).
- To manufacture durable coral concretes which can survive in the ocean environment with high concentrations of chloride, magnesia and sulphate ions and varying temperatures,

the use of cementitious compounds such as fly ash, silica fume, slag and fibres has been shown useful (Wang et al, 2018).

- The strength grade of coral concrete is relatively low, about 30MPa, which could be increased by increasing the cement content or adding a superplasticiser. The properties of coral concrete are somewhere between that of lightweight aggregate concrete and that of normal concrete (Liu at al 2018).
- The failure pattern of coral aggregate concrete is brittle because of the porous coral aggregate, while those of natural and recycled aggregate concretes are relatively ductile (Huang et al, 2018).
- Pre-wetted coral aggregate can gradually release the water absorbed before and during the cement hydration process, enhancing the interface bonding between aggregate and cement matrix (Zhou et al, 2019).
- By reducing the amount of coral gravel and blending of micro-coral sand and coral sand, an ultra-high performance concrete (UHPC) can be developed which has been shown to have better durability against chloride and sulphate attacks (Wang et al, 2017).
- The coral concrete exhibits high-early strength or rapid hardening phenomena for the 7 days compressive strength attains 90% of that at 28 days. The brittleness of coral concrete is more evident than that of conventional or lightweight concrete due to the high compressibility and low crushing strength of corals with remarkable intra-granular voids and highly irregular shape (Ma et al, 2019).

Available mix designs from the literature:

There is very limited data available for mix design of coral aggregate concrete. Few researchers have provided their trail mixes and obtained strength in the literature as shown in the table below:

Reference	Zhou et al, (2018)	Li et al, (2016)	Ma et al, (2019)
Cement	555 kg/m^3	440 kg/m^3	500 kg/m^3
Coral sand	543 kg/m^3	1555 kg/m^3	1300 kg/m^3
Coral Gravel	692 kg/m^3	-	-
Mix Ratio	1: 1: 1.2	1: 3.35: 0	1: 3.35: 0
Concrete Strength	38 MPa	27 MPa	40 MPa
Concrete Density	2095 kg/m^3	2020 kg/m^3	2000 kg/m^3
W/C ratio	0.55	0.59	0.48

From the above table, it can be seen that cement content is above 400 kg/m^3 for achieving the strength of 30 MPa or more. Two researchers have reported that better strength and durability is achieved by mixing the coral sand only (with small coral fragments) and by avoiding the coarse coral gravel (Li et al, 2016; Ma et al, 2019). The density of coral concrete was between normal weight and light weight aggregate concrete.

Based on these findings, the mix design of coral aggregate concrete has been determined and optimised so that not only the expected strength can be achieved but also the durability can also be ensured in the marine environment to increase resistance against cracking, chloride and sulphate attacks. To achieve this mix design, preliminary tests such as sieve analysis and density measurements of the provided coral aggregates were conducted. The details are presented in the upcoming sections

Preliminary Tests

1- Cylinder tests:

Two coral aggregate concrete cylinders were mixed and poured on the site in Vanuatu as per builder's mix proportion of cement 1: sand 1: gravel 2 with water cement ratio of 0.5 for testing in QUT materials lab to determine the strength and failure load. The details of the testing and results for cylinder specimens are as follows:

Data:

Cast Date : 12 January, 2019
Test Date : 9 February, 2019
Standard : AS1012.9 – 2014
Nominal Sample Size : 200mm high × 100mm diameter
Nominal Work Area : $7850mm^2$
Test Loading Rate : 20MPa/min
Pre-test Observations : Significant surface cracking is evident throughout sample. This may be due to the curing method utilised.

Test Results:

Sample Number	Failure Load (kN)	Compressive Strength (MPa)
1	204	26
2	229	29
Mean Strength		27.6 (CoV 8%)

The failure mode was shear dominant and cracking occurred through the coral aggregates showing the porousness and low strength of aggregates. This also implies low ductility of coral aggregate concrete. These results were helpful to optimise the proportions to achieve 25 MPa concrete.

2- Sieve analysis of aggregates:

Sieve analysis was conducted on the provided samples of coral sand and gravel from Vanuatu site. Density were also measured for the given samples.

Data:

Weight of coral sand	:	177 g
Compacted dry density of coral sand	:	1408 kg/m^3
Weight of coral gravel	:	199 g
Compacted dry density of coral gravel	:	928 kg/m^3
Test Date	:	10 March, 2019

Sieve analysis of coral sand:

The following table shows the sieve analysis data for coral sand sample:

Sieve size	Sand retained (gm)	% Retained	Cumulative % Retained	Cumulative % Passing
19	0	0	0.0	100.0
13.2	0	0	0.0	100.0
9.5	1	1	0.6	99.4
4.75	7	4	4.5	95.5
2.36	14	8	12.4	87.6
1.18	39	22	34.5	65.5
0.6	51	29	63.3	36.7
0.425	20	11	74.6	25.4
0.3	14	8	82.5	17.5
0.13	22	12	94.9	5.1
0.075	7	4	98.9	1.1
pan	2	1		

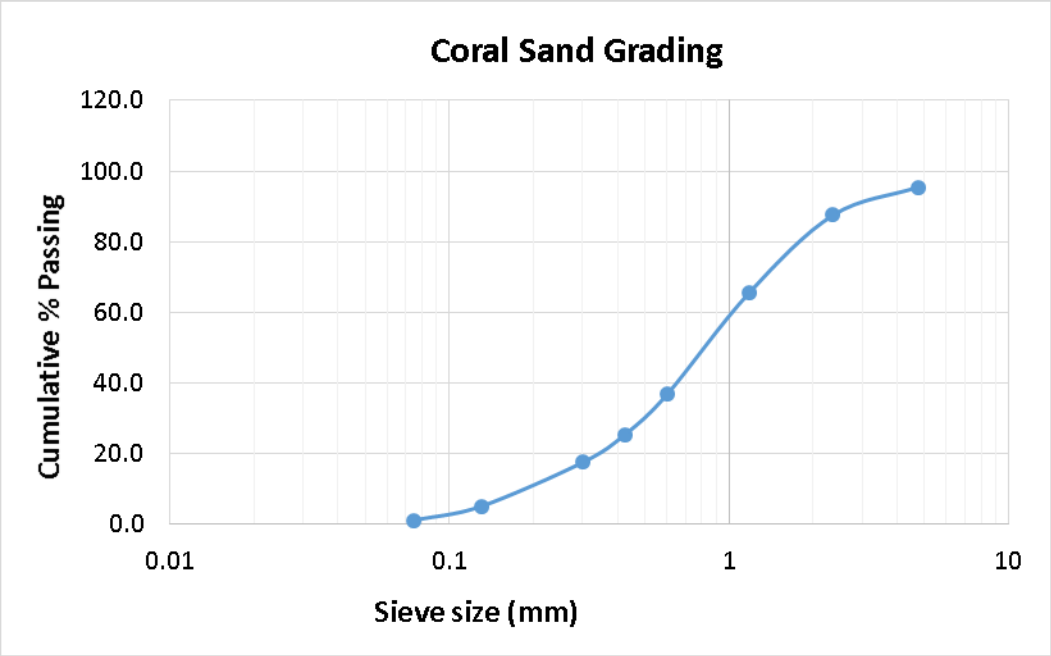

Fig 1: Grading curve of Coral Sand from Vanuatu

The grading in Fig. 1 shows that the particle size in coral sand varies from 0.075mm to 5mm. The fineness modulus of coral sand was measured as 4.7 higher than the normal sand (2.4-3.5). This shows the presence of coarse particles in the coral sand.

Sieve analysis of coral gravel:

The following table shows the sieve analysis data for coral gravel sample:

Sieve size	Gravel retained (gm)	% Retained	Cumulative % Retained	Cumulative % Passing
19	110	55.3	55.3	44.7
13.2	45	22.6	77.9	22.1
9.5	36	18.1	96.0	4.0
4.75	2	1.0	97.0	3.0
2.36	0	0.0	97.0	3.0
1.18	0	0.0	97.0	3.0
0.6	0	0.0	97.0	3.0
0.425	1	0.5	97.5	2.5
0.3	1	0.5	98.0	2.0
0.13	1	0.5	98.5	1.5
0.075	1	0.5	99.0	1.0
pan	2	1.0		

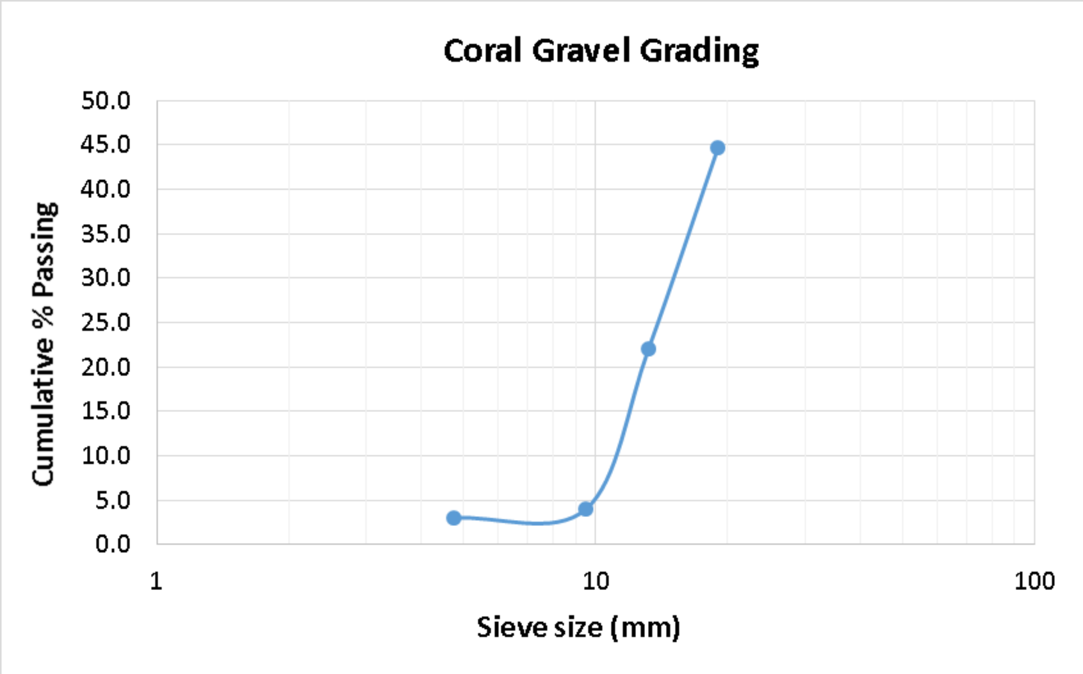

Fig 2: Grading curve of Coral Gravel from Vanuatu

The grading of gravel (Fig. 2) shows that the particle size in coral gravel varies from 5mm to 19mm. The aggregates are also well graded and rough in texture which is good for achieving better bond and strength. However, as mentioned earlier the porosity of coral aggregate influences the strength and durability of coral concrete greatly and high strength was shown to achieve in literature by reducing the amount of coral gravel (coarse aggregate) in the mix (Li et al 2016, Ma et al, 2019).

Mix Design

Mix design has been carried out based on the limited data from the experiments. Other required parameters including moisture content of coral aggregates, absorption capacity of coral aggregates, suitable slump and water cement ratio were picked from the literature. The quantity of coral aggregates were selected somewhere in between what were required for normal weight and light weight concrete. The mix design parameters and calculated contents are given as below:

Parameter	Magnitude	Source	Comment
Required strength	25 MPa	Client	
Required slump	100 mm	ACI 211.1-91	Suitable for suspended slabs
Sp. gravity of cement	3.15	ACI 211.1-91	OPC
Max aggregate size	19 mm	QUT testing	
Density of coral gravel	928 kg/m^3	QUT testing	
Moisture content of coral gravel	5%	Zhou et al (2019)	Washed (pre-wetted) before mixing
Absorption capacity of coral gravel	10%	Zhou et al (2019)	
Density of coral sand	1408 kg/m^3	QUT testing	
Moisture content of coral sand	1%	Zhou et al (2019)	Wetting under light rain
Absorption capacity of coral sand	9%	Zhou et al (2019)	
Fineness modulus of coral sand	4.7	QUT testing	Relatively higher than normal sand
Water content	205 kg/m^3	ACI 211.1-91	For max aggregate size 19mm & slump = 100mm
Water/cement ratio	0.54	ACI 211.1-91	For 25-32MPa concrete
Air content	2%	ACI 211.1-91	For max aggregate size 19mm & slump = 100mm
Cement content	308 kg/m^3	Calculated	From water content & W/C ratio
Dry volume of coral gravel	0.4 m^3	ACI 211.1-91 ACI 211.2-91	An intermediate value between normal & lightweight concrete
Volume of coral sand	0.38 m^3	Calculated	By subtracting volume of all other contents from 1m^3 of concrete
Coral gravel content (saturated condition)	408 kg/m^3	Calculated	Using measured density and selected absorption capacity
Coral sand content (saturated condition)	765 kg/m^3	Calculated	Using measured density and selected absorption capacity

Adjustments for water content and final quantities:

The quantities of aggregates (coral sand and gravel) and water were adjusted for the anticipated moisture due to wetting of aggregates. The amount of gravel and sand was increased while water content was decreased to account for selected moisture content in the aggregates from the literature as mentioned in the table above.

Final quantities of mix proportions are given below:

Cement	:	380 kg/m^3 of concrete
Coral sand	:	772 kg/m^3 of concrete
Coral gravel	:	429 kg/m^3 of concrete
Water	:	177 kg/m^3 of concrete
Coral Concrete Density	:	1757 kg/m^3
Mix ratio	:	1: 2.0: 1.1
W/C ratio	:	0.47

Optimisation of Mix Design

The mix design quantities shown in the previous section were optimised based on the literature findings to increase the density of the mix as well as the ratio of coral aggregates. The initial density was only 1757 kg/m^3, coral aggregate were increased to increase the density of the mix. Cement content was not increased as the required strength is only 25MPa which is lower than the literature findings. W/C ratio was also kept unchanged to achieve the required strength and durability.

Optimised quantities of mix proportions are given below:

Cement	**:**	**380 kg/m^3 of concrete**
Coral sand	**:**	**760 kg/m^3 of concrete**
Coral gravel	**:**	**532 kg/m^3 of concrete**
Water	**:**	**180 kg/m^3 of concrete**
Coral Concrete Density	**:**	**1850 kg/m^3**
Mix ratio	**:**	**1: 2.0: 1.4**
W/C ratio	**:**	**0.47**

The calculated quantities are indicative quantities for a trial mix and slight adjustments can be made to achieve the desired workability and strength.

Summary and Conclusions

Major conclusions from this research are given below:

- The mix design for coral aggregate concrete has been conducted for 25MPa ultimate design strength of suspended slabs. The quantities of cement, water, coarse aggregates (coral gravel) and fine aggregates (coral sand) were calculated based on the limited test data available and selected/assumed values from the literature research.
- The water and cement content was chosen for the required slump, w/c ratio and strength of 25MPa. The volume of coarse aggregate was chosen based on the finesse modulus of sand of 4.7 which shows coarseness in sand and hence reduced the volume of coarse aggregates in the mix.
- The initial mix was found less dense as compared to what has been shown in the literature. The density of the mix was increased to 1850 kg/m^3 by increasing the amount of coarse aggregate. The mix was optimised to achieve the mix ratios indicated in the literature for required strength of around 27-30 MPa.
- Cement and water content were not changed during optimisation to achieve the required strength and durability.
- The calculated mix is for trial and indicative, values can be slightly adjusted to achieve the required workability and strength.

References

1. Wang A, Lyu B, Zhang Z, Liu K, Xu H and Sun D. (2018). The development of coral concretes and their upgrading technologies: A critical review. Construction and Building Materials 187: 1004–1019.
2. Liu J, Ou Z, Peng W, Guo T, Deng W and Chen Y. (2018). Literature Review of Coral Concrete. Arabian Journal of Science and Engineering 43:1529–1541.
3. Huang Y, He X, Sun H, Sun Y, Wang Q. (2018). Effects of coral, recycled and natural coarse aggregates on the mechanical properties of concrete. Construction and Building Materials 192: 330–347.

4. Zhou W, Zhou Y, Feng P, Wang Z, Wang J, and Song P. (2019). Mechanical and Durability Properties of Coral Aggregate Concrete. American Concrete Institute, ACI special edition SP330: 175-188.
5. Wang X, Yu R, Shui Z, Song Q, Zhang Z. (2017). Mix design and characteristics evaluation of an eco-friendly Ultra-High Performance Concrete incorporating recycled coral based materials. Journal of Cleaner Production 165:70-80.
6. Ma L, Li Z, Liu J, Duan L, and Wua J. (2019). Mechanical properties of coral concrete subjected to uniaxial dynamic compression. Construction and Building Materials 199: 244–255.
7. Li WF, Guan J, Ma SH, et al (2016). Application of sea sand and coral reefs in the production of concrete mixed with seawater. Concrete 5: 148–152.
8. ACI Committee 211.1-91, Standard practice for selecting proportions for normal, heavyweight and mass concrete, Part 1, ACI Manual of Concrete Practice, 1994.
9. ACI Committee 211.2-91, Standard practice for selecting proportions for structural lightweight concrete, Part 1, ACI Manual of Concrete Practice, 1994.