A Report on the Use of Recycled Aggregates in Low Grade Concrete

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FOREWORD

The Public Works Central Laboratory (PWCL) of the Materials Division has conducted a series of material testing and trial concrete mixes with the recycled aggregates from Kai Tak and Tseung Kwan O. This study is to investigate the use of recycled aggregates as the main constituents of low-grade structural concrete. The objectives are to collect data/information to support the proposed amendments to the General Specifications for Civil Engineering Works (Hong Kong Government, 1992) in promoting the use of recycled aggregates in Civil and Structural Engineering Works.

This study is initiated by Standing Committee on Concrete Technology (SCCT) and two other local universities are invited to participate in the tests. They are the University of Hong Kong and the Hong Kong University of Science and Technology. The planning and overall supervision of the project is carried out by Mr. K.K. LIU. Testing and specimen preparation were performed by Mr. T.F. MAN and Mr. W.K. CHOI from Concrete Unit of PWCL. This report is prepared by Mr. W.H. TAM and finalized by Mr. K.K. LIU. Their contribution to this investigation is gratefully acknowledged.

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ABSTRACT

At the request of the Standing Committee on Concrete Technology (SCCT), the Public Works Central Laboratory of the Materials Division, GEO, conducted an investigation to study the properties of recycled aggregates from Kai Tak and Tseung Kwan O, and determine the possibility of using the recycled aggregates as the main constituents for low-grade structural concrete.

The laboratory trial involved 7 initial mix design with 20mm coarse recycled aggregates. These mix designs are initiated by varying the mix proportion of cement and water content of the Standard Mix prepared by SCCT. To improve the workability and consistency of the mix after the initial series of trials, 1/3 of the 20mm aggregates were replaced by 10mm aggregates and this formed the alternative mix design series.

The University of Hong Kong and the Hong Kong University of Science and Technology were invited to participate in the laboratory trial in an effort to provide the inter-laboratory test results for this study.

Due to the large water absorption rate, the recycled aggregates were immersed in clear water to attain saturated surface dry (SSD) condition prior to mixing.

Although, there are variation in the results of the trials between laboratories, some consistent results were obtained. The 100kg cement specified in the draft particular specification for concrete with recycled coarse aggregates proved to be useful since all Mixes with 100kg of cement have strength above 20MPa.

The water content in the Standard Mix for 20 MPa concrete containing 100kg cement shall be not more than 60kg. To gain better workability and consistency of the concrete, coarse aggregates containing both 20mm and 10mm size in 2 to 1 ratios are recommended for inclusion in the mix. Furthermore, a more cost-effective way to remove the non-inert portion of the construction and demolition materials is required in order to improve the quality of the concrete.

CONTENTS

1. INTRODUCTION

The use of using recycled aggregates recovered from construction and demolition (C&D) materials can save resources and reduce the amount of wastes going to reclamation and landfill sites, thus protecting the environment.

C&D materials are a mixture of inert and non-inert materials arising from construction and demolition activities, such as site clearance, renovation, demolition and civil engineering and building works. The inert portions include materials such as soil and rock, concrete, asphalt and brick, which will not decompose. The non-inert portions include decomposable materials such as bamboo, timber, paper and garbage.

The continued development of the Hong Kong SAR has led to a significant increase in C&D materials. The inert portions should have been disposed of at the public filling areas for use as reclamation materials, and the non-inert portions to landfill sites. However, in the past large quantities of the inert portion have been disposed of at landfill sites, thus significantly reducing the overall life span of the landfill that was designed to accept municipal solid wastes.

In 1999, Civil Engineering Department (CED) conducted a desk study to investigate the opportunities for recycling C&D materials in the Hong Kong SAR. The preliminary findings indicated that it is possible to use recycled aggregates in unbound road base and low-grade concrete.

This study is the follow-up of the desk study to investigate the use of recycled aggregates in low-grade concrete through tests on trial mixes prepared at the laboratories. The physical properties of recycled aggregates were determined and compared with the draft compliance criteria (see Appendix I), which were prepared by Standing Committee on Concrete Technology (SCCT). The objective of the study is to collect data (density, absorption rate, percentage of foreign materials, compressive strength, etc.) to support the inclusion of these criteria in the General Specification for Civil Engineering Works (Hong Kong Government, 1992) in order to promote the use of recycled aggregates in civil engineering works.

2. TESTING PARTIES INVOLVED

There were three laboratories participated in the laboratory trials:

- the laboratory of the Civil and Structural Engineering Department of the University of Hong Kong (HKU).

- the laboratory of the Hong Kong University of Science and Technology (HKUST), and
- the Public Works Central Laboratory (PWCL).

The two universities, HKU and HKUST, were invited for participating in the laboratory trails as SCCT wished to collect more information, especially inter-laboratories test results, within a short period. Moreover, their independence and strong academic support were beneficial to this kind of investigation.

3. SOURCES OF RECYCLED AGGREGATES

The recycled aggregates (20mm & 10mm) were from Kai Tak and Tseung Kwan O. The Kai Tak aggregates were recovered from the demolition of the buildings and part of the runway at the Kai Tak Airport. Whereas the aggregates from Tseung Kwan O were processed from the demolition materials from various redevelopment sites in Eastern Kowloon area. However, the exact locations were not known.

4. PREPARATION OF RECYCLED AGGREGATES PRIOR TO MIXING

To minimise the variability in the conditions of the samples for the tests, saturated surface dry condition (SSD) was specified for preparing the samples. However, there were slight variations in achieving this condition among the laboratories. The methods adopted for preparing the recycled aggregates prior to mixing by different parties are as follows:

1. HKU - the recycled aggregates were immersed in water for about 10 minutes and then wiped dry with towel.
2. HKUST - the recycled aggregates were immersed in water overnight and then wiped dry with towel.
3. PWCL - for initial mixes (see Section 5 below), the recycled aggregates were immersed in water overnight and then wiped dry with towel. However, for the 'A' series of mixes (see Section 5 below), no such preparation was made.

5. TYPE OF MIXES

In the first series of trials, concrete cube specimens of different mix designs were prepared. The slump as well as strength of the concrete at 7 and 28 days were measured. Seven mix

designs using single-sized aggregates (20mm) were prepared (hereafter named as the 'initial mixes', see Table 1). These mix designs were prepared by varying the cement and water contents while keeping the amount of fine and coarse aggregates constant (at 180 and 270 kg respectively). To improve the workability and consistency of the mix, 1/3 of the 20mm aggregates were replaced by 10mm aggregates in the second series of trials (identified as the 'A' mix series, such as mixes 1A, 2A, ...etc.). The proportions of other materials were kept the same, but plasticizer was added during mixing to improve the workability.

6. TEST RESULTS

All test results are summarised in Tables 2 - 7. The results of tests on concrete containing aggregates from Tseung Kwan O are summarised in Tables 2 and 4, and those on concrete containing from aggregates from Kai Tak are summarised in Tables 3 and 5. The material properties of the recycled aggregates from Tseung Kwan O and Kai Tak are summarised in Tables 6 and 7 respectively.

7. FINDINGS AND OBSERVATIONS

The findings and observations made from this study are summarised as follows:

A. Initial mix design, Mix No. 1-7
(20mm single size aggregates at SSD condition)

1. All concrete mixes, except Mix No. 1 and Mix No. 2 prepared by HKUST and PWCL respectively from aggregates from Tseung Kwan O, have attained strength greater than 20 MPa at 28 days. The low strength might be due to the poor cohesiveness of the concrete as a result of the relatively large amount of coarse aggregates and the low cement content,
2. Although appreciable variations in strength were observed among the cubes from the same type of mix prepared by different laboratories, the concrete strength was still found inversely related to the water cement ratio within each laboratory (i.e. the higher the water cement ratio the lower the strength),
3. For the same amount of cement, the slump increased with the water content,
4. The density of concrete containing recycled aggregates was less than that of the normal concrete (2,400 kg/m^3). Furthermore, the density of concrete containing recycled aggregates from Tseung Kwan O (about 2,300 kg/m^3) is generally slightly higher than that from Kai Tak (about 2,250 kg/m^3). However, the density of both

types of concrete can meet the draft compliance criterion (minimum density of 2,000 kg/m^3).

5. Foreign materials such as plastic sheets, cigarette butts, bricks and dust were found in the recycled aggregates. This could affect the density, strength and possibly the durability of the concrete. The maximum content of wood and that of the other foreign materials were found to be 1.13% and 2.53%, which were larger than the permissible limits of 0.5% and 1% respectively.

B. Alternative mix design, Mix No. 1A-8A
(2/3 20mm aggregates + 1/3 10mm aggregates, with admixture)

1. The large absorption value of the recycled aggregates could increase the amount of water for concrete mixing. Also, longer time would be needed for the mixing as more water would have to be added when recycled aggregates were used for concrete production. The actual water/cement ratio of the mix may not be accurately determined if insufficient time is allowed for the pre-wetting of the recycled aggregates.
2. Pre-soaking and drying of the recycled aggregates with towels to attain the SSD condition before mixing is not a cost-effective process in routine production. Furthermore, if the recycled aggregates are not fully saturated in this process, the strength development will be affected as less water will be used in the hydration of cement (see the variation in strength in Tables 4 & 5).
3. Since only a small quantity of concrete was mixed in the trials, a relatively large amount of admixture added might have been absorbed in contact with the surfaces of the mixer and other equipment.

8. CONCLUSIONS

Although there are variations in the results of the trials between laboratories, some consistent results were obtained with the conclusions:

1. The 100 kg of cement specified in the draft particular specification for concrete with recycled coarse aggregates was found to be adequate since all Mixes with 100 kg of cement have attained strength greater than 20 MPa.
2. The water content in the Standard Mix for 20 MPa concrete containing 100 kg of cement shall be not more than 60 kg.
3. To improve the workability and consistency of the concrete, coarse aggregates of both 20 mm and 10 mm size and in 2 to 1 ratio are recommended to be included in

the mix.

4. To improve the quality of the concrete, a more cost-effective way to remove the non-inert portions of the construction and demolition materials is required.

APPENDIX

Appendix I

Draft compliance criteria of recycled aggregates

Mandatory Requirements	Limits	Testing Method
Minimum dry particle density (kg/m^3)	2000	BS 812: Part 2
Max. water absorption	10 %	BS 812: Part 2
Max. content of wood and other material less dense than water	0.5 %	Manual sorting in accordance with BRE Digest 433
Max. content of other foreign materials (e.g. metals, plastics, clay lumps, asphalt and tar, glass etc)	1 %	
Max. fines	4 % *Note 1*	BS 812: Section 103.1
Max. content of sand (< 4 mm) (% m/m)	5 %	BS 812: Section 103.1
Max content of sulphate (%m/m)	1	BS 812: Part 118
Flakiness index	40 % - *Note 2*	BS 812: Section 105.1
10% fines test	100 kN- *Note 3*	BS 812: Part 111
Grading	Table 3 of BS 882:1992	
Maximum Chloride content	Table 7 of BS 882 – 0.05% by mass of chloride ion of combined aggregate – *Note 4*	

Note 1 Filler (< 0.063 mm)should be less than 2% in Rilem Specification. BS 882 says that fines passing 75μm sieve shall not exceed 4 %. The latter requirement is easier to satisfy.

Note 2 Section 16.08 (3) states that flakiness shall not exceed 35% whereas BS 882 states that it shall not exceed 40 for crushed rock or crushed gravel.

Note 3 Section 16.08(3) states that the 10% fines value shall be at least 100 kN. BS 882 states that the 10% fines value to be 50 for concrete not subjected to wearing. BRE Digest 433 states that 70kN is achievable in recycled aggregate derived from brickwork, and 100 kN for those derived from crushed concrete.
In recent tests carried out on recycled aggregates derived from old concrete,100 kN can be satisfied.

Note 4 BRE Digest 433 recommends to determine acid soluble chloride rather than water soluble chloride.

LIST OF TABLES

Table 1 - Proportion of Different Concrete Mixes with Recycled Coarse Aggregates

Mix Number	1	2	3	4	5	6	7
Ordinary Portland Cement (kg)	60	60	80	80	100	100	100
Fine Aggregates (kg)	180	180	180	180	180	180	180
Coarse Aggregates (kg) 20mm	270	270	270	270	270	270	270
Water (kg)	30	40	40	50	40	50	60
Aggregate/Cement Ratio	7.5	7.5	5.6	5.6	4.5	4.5	4.5
Water/Cement Ratio	0.50	0.67	0.50	0.63	0.40	0.50	0.60

Notes:

1. The slump, density and 7 and 28 days strength of the concrete mixes were measured, and the slump of concrete was targeted at 75mm.
2. For initial mixes, 20 mm coarse aggregates were used.
3. For alternative mixes, 1/3 of the 20mm coarse aggregates were replaced by 10mm coarse aggregates.

Table 2 - Summary of Test Results on Concrete Prepared from 20mm Aggregates from Tseung Kwan O

			Mix No. 1			Mix No. 2			Mix No. 3			Mix No. 4			Mix No. 5			Mix No. 6			Mix No. 7		
			HKU	PWCL	HKUST	HKU	PWCL	HKUST	HKU	PWCL	HKUST	HKU	PWCL	HKUST	HKU	PWCL	HKUST	HKU	PWCL	HKUST	HKU	PWCL	HKUST
7 Days	**Density**	Cube 1	2360.0	2334.0	2105.0	2340.0	2302.0	2126.0	2340.0	2300.0	2250.0	2330.0	2370.0	2291.0	2360.0	2333.0	2141.0	2330.0	2288.0	2295.0	2300.0	2275.0	2256.0
	(Kg/m3)	Cube 2	2360.0	2318.0	2111.0	2320.0	2272.0	2146.0	2350.0	2317.0	2277.0	2330.0	2272.0	2298.0	2370.0	2343.0	2151.0	2330.0	2289.0	2308.0	2310.0	2284.0	2287.0
	Mean of pair		2360.0	2326.0	2108.0	2330.0	2287.0	2136.0	2345.0	2308.5	2263.5	2330.0	2321.0	2294.5	2365.0	2338.0	2146.0	2330.0	2288.5	2301.5	2305.0	2279.5	2271.5
	Average of 3 labs		2264.7			2251.0			2305.7			2315.2			2283.0			2306.7			2285.3		
	Strength	Cube 1	33.0	23.0	9.2	23.0	13.7	13.8	34.5	22.1	37.8	26.0	15.5	23.0	47.5	36	49.1	38.5	24.6	39.5	26.5	17.0	25.8
	(MPa)	Cube 2	34.0	22.5	10.5	23.0	12.8	21.9	35.5	23.2	37.3	24.5	16.0	24.8	51.5	36.4	48.7	37.5	25.0	37.9	27.0	16.7	27.3
	Mean of pair		33.5	22.8	9.9	23.0	13.3	17.9	35.0	22.7	37.6	25.3	15.8	23.9	49.5	36.2	48.9	38.0	24.8	38.7	26.8	16.9	26.6
	Average of 3 labs		22.0			18.0			31.7			21.6			44.9			33.8			23.4		
28 Days	**Density**	Cube 1	2350.0	2323.0	2153.0	2340.0	2290.0	2180.0	2350.0	2314.0	2320.0	2350.0	2283.0	2333.0	2370.0	2355.0	2225.0	2340.0	2305.0	2365.0	2320.0	2285.0	2304.0
	(Kg/m3)	Cube 2	2360.0	2350.0	2161.0	2340.0	2310.0	2185.0	2350.0	2346.0	2327.0	2340.0	2323.0	2336.0	2360.0	2345.0	2238.0	2340.0	2314.0	2376.0	2300.0	2287.0	2309.0
	Mean of pair		2355.0	2336.5	2158.0	2340.0	2300.0	2182.5	2350.0	2330.0	2323.5	2345.0	2303.0	2334.5	2365.0	2350.0	2231.5	2340.0	2309.5	2370.5	2310.0	2286.0	2306.5
	Average of 3 labs		2283.2			2274.2			2334.5			2327.5			2315.5			2340.0			2300.8		
	Strength	Cube 1	40.0	30.9	18.0	30.5	17.1	28.4	46.0	29.8	45.3	33.5	21.7	34.0	60.5	46.5	61.6	48.5	31.8	46.2	35.5	23.6	33.5
	(MPa)	Cube 2	43.0	31.6	19.8	31.5	17.5	27.7	46.0	30.3	47.7	35.0	22.2	32.7	58.5	46.2	62.7	47.0	34.2	47.7	38.0	24.3	32.0
	Mean of pair		41.5	31.3	18.9	31.0	17.3	28.1	46.0	30.1	46.5	34.3	22.0	33.4	59.5	46.4	62.2	47.8	33.0	47.0	36.8	24.0	32.8
	Average of 3 labs		30.6			25.5			40.9			29.9			56.0			42.6			31.2		
Slump (mm)			0.0	0.0	56.0	5.0	40.0	18.0	5.0	35.0	19.0	35.0	80.0	43.0	15.0	0.0	14.0	35.0	55.0	35.0	120.0	110.0	178.0
Average of 3 labs			12.0			21.0			19.7			52.7			9.7			41.0			136.0		

Notes:

1. For initial mix design, Mix No. 1-7, no plasticizer was added.
2. The recycled aggregates were immersed in clean water for a certain period and dried with towel to reach the SSD condition before mixing.
3. Stone fines from Ka Wah Quarry at the Anderson Road were used as fine aggregates.

Table 3 - Summary of Test Results on Concrete Prepared from 20mm Aggregates from Kai Tak

			Mix No. 1			Mix No. 2			Mix No. 3			Mix No. 4			Mix No. 5			Mix No. 6			Mix No. 7		
			HKU	PWCL	HKUST	HKU	PWCL	HKUST	HKU	PWCL	HKUST	HKU	PWCL	HKUST	HKU	PWCL	HKUST	HKU	PWCL	HKUST	HKU	PWCL	HKUST
7 Days	**Density**	Cube 1	2330.0	2303.0	2016.0	2270.0	2264.0	2195.0	2300.0	2299.0	2118.0	2260.0	2258.0	2208.0	2310.0	2313.0	2086.0	2290.0	2279.0	2247.0	2270.0	2251.0	2252.0
	(Kg/m3)	Cube 2	2330.0	2305.0	2033.0	2290.0	2247.0	2197.0	2300.0	2295.0	2123.0	2270.0	2270.0	2221.0	2320.0	2301.0	2094.0	2290.0	2280.0	2270.0	2260.0	2276.0	2268.0
	Mean of pair		2330.0	2304.0	2024.5	2280.0	2255.5	2196.0	2300.0	2297.0	2119.0	2265.0	2264.0	2214.5	2315.0	2307.0	2090.0	2290.0	2279.5	2258.5	2265.0	2263.5	2260.0
	Average of 3 labs		2219.5			2243.8			2238.7			2247.8			2237.3			2276.0			2262.8		
	Strength	Cube 1	35.5	30.6	10.7	23.0	17.1	21.1	35.0	29.6	35.8	25.5	18.3	22.4	50.0	43.0	51.7	38.0	31.6	38.8	26.5	20.6	23.5
	(MPa)	Cube 2	37.0	28.5	17.0	22.5	16.8	21.1	37.0	30.0	35.7	25.5	19.0	23.6	49.0	42.6	48.5	37.0	30.8	35.6	28.5	20.1	26.1
	Mean of pair		36.3	29.6	13.9	22.8	17.0	21.1	36.0	29.8	35.8	25.5	18.7	23.0	49.5	42.8	50.1	37.5	31.2	34.7	27.5	20.4	24.8
	Average of 3 labs		26.6			20.3			33.9			22.4			47.5			34.5			24.2		
28 Days	**Density**	Cube 1	2320.0	2345.0	2067.0	2280.0	2284.0	2251.0	2290.0	2288.0	2166.0	2270.0	2252.0	2275.0	2320.0	2291.0	2154.0	2290.0	2287.0	2292.0	2270.0	2202.0	2285.0
	(Kg/m3)	Cube 2	2330.0	2324.0	2091.0	2290.0	2289.0	2263.0	2310.0	2291.0	2178.0	2280.0	2253.0	2278.0	2320.0	2304.0	2168.0	2290.0	2290.0	2334.0	2250.0	2246.0	2290.0
	Mean of pair		2325.0	2334.5	2079.0	2285.0	2286.5	2257.0	2300.0	2289.5	2172.0	2275.0	2252.5	2276.5	2320.0	2297.5	2161.0	2290.0	2288.5	2313.0	2260.0	2224.0	2287.5
	Average of 3 labs		2246.2			2276.2			2253.8			2268.0			2259.5			2297.2			2257.2		
	Strength	Cube 1	43.0	37.0	34.5	29.5	22.8	29.7	47.5	37.7	43.8	33.0	24.4	29.8	58.5	52.3	55.6	47.5	42.5	40.2	38.5	27.1	33.3
	(MPa)	Cube 2	45.0	36.9	41.5	30.5	22.5	28.9	47.0	38.7	45.6	33.5	24.5	31.2	59.5	51.2	57.8	47.5	41.0	44.8	37.5	27.8	32.3
	Mean of pair		44.0	37.0	38.0	30.0	22.7	29.3	47.3	38.2	44.7	33.3	24.5	30.5	59.0	51.8	56.7	47.5	41.8	42.5	38.0	27.5	32.8
	Average of 3 labs		39.7			27.3			43.4			29.4			55.8			43.9			32.8		
Slump (mm)			0.0	0.0	14.0	5.0	0.0	20.0	5.0	0.0	13.0	10.0	50.0	44.0	5.0	0.0	10.0	20.0	20.0	38.0	40.0	70.0	178.0
Average of 3 labs			4.7			8.3			6.0			34.7			5.0			26.0			96.0		

Notes:

1. For initial mix design, Mix No. 1-7, no plasticizer was added.
2. The recycled aggregates were immersed in clean water for a certain period and dried with towel to reach the SSD condition before mixing.
3. Stone fines from Ka Wah Quarry at the Anderson Road were used as fine aggregates.

Table 4 - Summary of Test Results on Concrete Prepared from 20mm and 10mm Aggregates[1] from Tseung Kwan O

			Mix No. 1A			Mix No. 2A			Mix No. 3A			Mix No. 4A			Mix No. 5A			Mix No. 6A			Mix No. 7A			Mix No. 8A		
			HKU	PWCL	HKUST	HKU	PWCL	HKUST	HKU	PWCL	HKUST	HKU	PWCL	HKUST	HKU	PWCL	HKUST	HKU	PWCL	HKUST	HKU	PWCL	HKUST	HKU	PWCL	HKUST
7 Days	Density	Cube 1										2290.0	2356.0		2330.0			2310.0	2343.0		2280.0				2277.0	
	(Kg/m3)	Cube 2										2280.0	2346.0		2330.0			2310.0	2329.0		2280.0				2295.0	
	Mean of pair											2285.0	2351.0		2330.0			2310.0	2336.0		2280.0				2286.0	
	Average of 3 labs											2318.0			2330.0			2323.0			2280.0			2286.0		
	Strength	Cube 1										20.4	40.4		43.5			34.5	47.7		26.0				23.7	
	(MPa)	Cube 2										19.5	39.4		44.5			36.0	48.9		23.5				24.2	
	Mean of pair											20.0	39.9		44.0			35.3	48.3		24.8				24.0	
	Average of 3 labs											29.9			44.0			41.8			24.8			24.0		
28 Days	Density	Cube 1										2280.0	2355.0		2330.0			2320.0	2375.0		2290.0				2294.0	
	(Kg/m3)	Cube 2										2290.0	2366.0		2330.0			2310.0	2362.0		2280.0				2270.0	
	Mean of pair											2285.0	2360.5		2330.0			2315.0	2368.5		2285.0				2282.0	
	Average of 3 labs											2322.8			2330.0			2341.8			2285.0			2282.0		
	Strength	Cube 1										27.5	52.1		52.0			45.0	62.6		33.0				31.8	
	(MPa)	Cube 2										27.0	48.4		50.5			45.0	60.8		32.5				30.8	
	Mean of pair											27.3	50.3		51.3			45.0	61.7		32.8				31.3	
	Average of 3 labs											38.8			51.3			53.4			32.8			31.3		
Slump (mm)												55.0	50.0		95.0			85.0	120.0		90.0				80.0	
Average of 3 labs												52.5			95.0			102.5			90.0			80.0		
Admixture added (ml) per 100 kg cement												150.0	2364.4		1500.0			600.0	2608.9		0.0				0.0	

Notes:

1. Two-third of the aggregates were 20mm size and one-third were 10mm.
2. Mix with "A" is similar to the original mix except that 1/3 of the 20mm aggregates were replaced by 10 mm aggregates and plasticizer, Daracem 100, was added to the concrete mix.
3. Stone fines from Ka Wah Quarry at the Anderson Road were used as the fine aggregates.
4. Mix 8A has same mix proportion as Mix 7A, except that additional 10 kg of water was added to the mix and the total amount of water is 70 kg.
5. Mixes 1A, 2A & 3A were not mixed due to low workability as seen in original mixes.
6. The HKU pre-soaked the recycled aggregates and dried them with towel to achieve SSD condition before mixing.
7. The PWCL took into acount the absorption value of the recycled aggregates in adjusting the amount of water for mixing.
8. As only a small quantity of concrete was mixed in the trials, a relative large amount of admixture added might have been absorbed in contact with the surface of the mixer and other equipment.

Table 5 - Summary of Test Results on Concrete Prepared from 20mm and 10mm Aggregates[1] from Kai Tak

			Mix No. 1A			Mix No. 2A			Mix No. 3A			Mix No. 4A			Mix No. 5A			Mix No. 6A			Mix No. 7A			Mix No. 8A		
			HKU	PWCL	HKUST	HKU	PWCL	HKUST	HKU	PWCL	HKUST	HKU	PWCL	HKUST	HKU	PWCL	HKUST	HKU	PWCL	HKUST	HKU	PWCL	HKUST	HKU	PWCL	HKUST
7 Days	Density	Cube 1										2270.0	2242.0		2310.0	2333.0		2280.0	2296.0		2250.0	2262.0			2238.0	
	(Kg/m3)	Cube 2										2260.0	2261.0		2310.0	2281.0		2270.0	2280.0		2250.0	2287.0			2239.0	
	Mean of pair											2265.0	2251.5		2310.0	2307.0		2275.0	2288.0		2250.0	2274.5			2238.5	
	Average of 3 labs											2258.3			2308.5			2281.5			2262.3			2238.5	
	Strength	Cube 1										26.0	26.8		51.0	50.1		38.5	38.4		28.0	25.8			17.3	
	(MPa)	Cube 2										27.5	27.9		51.5	49.2		38.0	37.8		27.0	25.6			17.4	
	Mean of pair											26.8	27.4		51.3	49.7		38.3	38.1		27.5	25.7			17.4	
	Average of 3 labs											27.1			50.5			38.2			26.6			17.4	
28 Days	Density	Cube 1										2280.0	2267.0		2310.0	2297.0		2270.0	2273.0		2240.0	2237.0			2243.0	
	(Kg/m3)	Cube 2										2260.0	2246.0		2320.0	2326.0		2270.0	2280.0		2260.0	2242.0			2223.0	
	Mean of pair											2270.0	2256.5		2315.0	2311.5		2270.0	2276.5		2250.0	2239.5			2233.0	
	Average of 3 labs											2263.3			2313.3			2273.3			2244.8			2233.0	
	Strength	Cube 1										35.5	33.2		59.0	58.7		47.5	46.5		37.0	28.2			24.4	
	(MPa)	Cube 2										36.5	35.9		60.0	57.6		49.5	45.6		37.5	33.4			25.1	
	Mean of pair											36.0	34.6		59.5	58.2		48.5	46.1		37.3	30.8			24.8	
	Average of 3 labs											35.3			58.8			47.3			34.0			24.8	
Slump (mm)												47.5	30.0		60.0	85.0		62.5	60.0		65.0	55.0			125.0	
Average of 3 labs												38.8			72.5			61.3			60.0					
Admixture added (ml) per 100 kg cement												375.0	788.1		2000.0	2052.3		600.0	1043.6		0.0	0.0			0.0	

Notes:

1. Two-third of the aggregates were 20mm size and one-third were 10mm.
2. Mix with "A" is similar to the original mix except that 1/3 of the 20mm aggregates were replaced by 10 mm aggregates and plasticizer, Daracem 100, was added to the concrete mix.
3. Stone fines from Ka Wah Quarry at the Anderson Road were used as the fine aggregates.
4. Mix 8A has same mix proportion as Mix 7A, except that additional 10 kg of water was added to the mix and the total amount of water is 70 kg.
5. Mixes 1A, 2A & 3A were not mixed due to low workability as seen in original mixes.
6. The HKU pre-soaked the recycled aggregates and dried them with towel to achieve SSD condition before mixing.
7. The PWCL took into acount the absorption value of the recycled aggregates in adjusting the amount of water for mixing.
8. As only a small quantity of concrete was mixed in the trials, a relative large amount of admixture added might have been absorbed in contact with the surface of the mixer and other equipment.

Table 6 - Material Properties of Recycled Aggregates from Tseung Kwan O

Item No.	Type of test	Limits[3]	HKU			PWCL			HKUST		
			Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
1	Minimum dry particle density (kg/m^3)	Min. 2000	2452	2430	2436	2430	2430	2440	2352	2510	2401
			2439			2433			2421		
2	Maximum water absorption (%)	Max. 10%	3.02	3.12	3.34	3.10	3.10	3.10	3.02	3.12	3.34
			3.16			3.10			3.16		
3	Maximum content of wood and other material less dense than water (%)	Max. 0.5%	1.30	1.20	0.90	0.03	0.06	0	0.08	0.12	0.02
			1.13			0.03			0.07		
4	Maximum content of other foreign materials (%) (e.g. metals, plastics, clay lumps, asphalt and tar, glass etc.)	Max. 1%	3.00	2.50	2.10	0.70	0.90	0.20	0.46	0.49	0.42
			2.53			0.60			0.46		
5	Maximum Content of fines (% by mass)	Max. 4%	0.50	0.40	0.40	0.20	0.30	0.50	0.01	0.02	0.09
			0.43			0.33			0.04		
6	Maximum content of sand (<4mm) (% by mass)	Max. 5%	1.30*	0.90*	0.90*	2.00*	1.00*	1.00*	0.02	0.05	0.34
			1.03*			1.33*			0.14		
7	Maximum content of sulphate (% by mass)	Max. 1%				0.23	0.30		0.18	0.20	0.18
						0.27			0.19		
8	Flakiness index (%)	Max. 40%	17.0	20.0	21.0	20.0	19.0	19.0	31.0	28.0	32.0
			19.3			19.3			30.3		
9	10% fines test (kN)	Min. 70 kN	142.0	141.0	135.0	120.0	130.0	130.0	118.0	120.0	115.0
			139.3			126.7			117.7		
10	Compliance with Table 3 of BS882:1992 for single-sized 20mm aggregates in terms of grading.	Yes / No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
11	Maximum chloride content - Table 7 of BS 882 % by mass of chloride ion in combined aggregate	Max. 0.05%				<0.0100	<0.0100		0.0106	0.0035	0.005
						<0.0100			0.0064		

* the value is for < 5 mm (sieve size).

Notes:

1. For Item 10, the limits for % passing through the 20mm sieve are 85-100 in accordance with Table 3 of BS 882.
2. The test results for Item 1 from HKUST have been revised as per their request.
3. The limits were in accordance with the draft particular specifications on recycled aggregates (see Appendix I).

Table 7 - Material Properties of Recycled Aggregates from Kai Tai

Item No.	Type of test	Limits	HKU			PWCL			HKUST		
			Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
1	Minimum dry particle density (kg/m^3)	Min. 2000	2257	2297	2281	2250	2260	2260	2267	2365	2398
			2278			2257			2343		
2	Maximum water absorption (%)	Max. 10%	5.70	5.00	5.30	6.00	6.20	6.10	5.87	5.10	5.70
			5.33			6.10			5.56		
3	Maximum content of wood and other material less dense than water (%)	Max. 0.5%	0.30	0.20	0.00	0.0	0.0	0.0	0.00	0.00	0.00
			0.17			0.00			0.00		
4	Maximum content of other foreign materials (%) (e.g. metals, plastics, clay lumps, asphalt and tar, glass etc.)	Max. 1%	0.00	0.00	0.80	0.00	0.02	0.30	0.00	0.05	0.00
			0.27			0.11			0.02		
5	Maximum Content of fines (% by mass)	Max. 4%	0.50	0.40	0.50	0.10	0.30	0.60	0.01	0.02	0.01
			0.47			0.33			0.01		
6	Maximum content of sand (<4mm) (% by mass)	Max. 5%	1.20*	0.80*	1.20*	1.00*	1.00*	1.00*	0.04	0.06	0.06
			1.07*			1.00*			0.05		
7	Maximum content of sulphate (% by mass)	Max. 1%				0.29	0.30		0.40	0.42	0.34
						0.30			0.39		
8	Flakiness index (%)	Max. 40%	9.0	10.0	14.0	10.0	10.0	8.0	15.0	16.0	18.0
			11.0			9.3			16.3		
9	10% fines test (kN)	Min. 70 kN	112.0	117.0	117.0	90.0	95.0	90.0	130.0	121.0	127.0
			115.3			91.7			126.0		
10	Compliance with Table 3 of BS882:1992 for single-sized 20mm aggregates in terms of grading.	Yes / No	No	Yes	Yes	Yes	Yes	Yes	No	No	No
11	Maximum chloride content - Table 7 of BS 882 % by mass of chloride ion in combined aggregate	Max. 0.05%				<0.0100	<0.0100		0.0014	0.0036	0.0085
						<0.0100			0.0045		

* the value is for < 5 mm (sieve size).

Notes:

1. For Item 10, the limits for % passing through the 20mm sieve are 85-100 in accordance with Table 3 of BS 882.
2. The test results for Item 1 from HKUST have been revised as per their request.
3. The limits were in accordance with the draft particular specifications on recycled aggregates (see Appendix I).