Durability Study for Normal Grade

Concrete with Recycle Aggregates

CONTENTS

construction products. Many international and local researchers have carried out numerous studies to investigate the potential usage of recycled aggregates. However there were not many studies focusing on the long-term effect on the properties of concrete produced with recycled aggregate. Therefore the objective of this study is to concentrate on the durability performance of recycled aggregate concrete.

ABSTRACT

The purpose of this project was to compare the properties of different mixes of concrete produced with natural aggregate and produced using recycled aggregate, with 20% and 100% replacement by weight, and with 0% and 35% PFA replacement. Concrete cubes, concrete cylinders and concrete prisms were cast for testing. The compressive strength of concrete at 7 and 28 days of age of concrete was determined. Accelerated bulk diffusion and profile grinding test were adopted to study chloride penetration. Shrinkage test was used to monitor the dimensional change of the specimens. Slump test was measured to indicate the change of workability. Other general properties of concrete were also studied such as young modulus of elasticity, water absorption and shrinkage.

The results showed that there is no noticeable difference of the properties of concrete with 20% recycled aggregate from that of natural aggregate concrete. However, the difference is significant for concrete with 100% recycled aggregate replacement.

1. INTRODUCTION

1.1. With reference to information provided by Civil Engineering and Development Department of Hong Kong SAR Government, there are more than 14 millions tones of construction and demolition (C&D) materials generated per year from local construction activities. If there are no beneficial uses, the materials become wastes and it will be a large environmental and financial pressure to treat and dispose them.

1.2. In fact, large proportion of these C&D materials can be recycled and become recycled concrete aggregates and granular materials for re-use in construction industry. In order to protect the environment and for sustainable development, it is the Government's determination to promote recycling and the use of recycled products as far as possible to save resources and reduce the amount of wastes going to reclamation and landfill sites.

1.3. 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. Recycled aggregate is arising from inert materials.

1.4. Many research results showed that when concrete products produced with recycled aggregate less than 20% replacement of the natural aggregate in concrete, the effect on the properties of concrete is little. However, when higher level of replacement, the effect becomes noticeable. One obvious effect is high water absorption of recycled aggregates which will affect the control of the free water cement ratio and the workability of fresh concrete and results in a higher shrinkage and creep of the hardened concrete when compared with the concrete prepared with natural aggregate. The extent of which the properties of concrete are affected by the use of recycled aggregate depends on the water absorption, crushing value and soundness of the recycled aggregate.

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

1.6. In 2001, CED conducted a study to investigate the use of recycled aggregates in low-grade concrete through tests on trial mixes prepared at the Public Works Central Laboratory (PWCL). 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 was 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.

1.7. This study is a follow-up study to investigate the long-term effect of replacing normal aggregate with recycled aggregate on the concrete durability.

2. OBJECTIVE

2.1. This study is to investigate the properties of recycled aggregate concrete in respect to durability in term of protection against chemical attack resistance under the following scopes.

2.2. Durability of Concrete

2.2.1. Durability of concrete is dependent upon the resistance of chemical, biological and physical attacks. Chemical attack can be external chemical penetration causing erosion of reinforcement and concrete, and internal alkali-aggregate reaction. Physical attack will be mainly abrasion, weathering, wetting and drying. Biological attack is the growth of plants and micro-organism in concrete. The impacts will be growth of biomass and generation of bio-gas in concrete and causing cracks.

2.2.2. In order to confine the scope, the objective of this study is to investigate the long-term effect on the durability of concrete in respect to structural serviceability with recycled aggregate in structural concrete and the scope is concentrated on the chemical attacks.

2.2.3. Although recycled materials for construction industry in Hong Kong can be classified as aggregate, asphalt, excavated materials, public fill, pulverized fuel ash, metals, glass, plastic, rubber, expended polystyrene, etc. The scope of this study will be limited to recycled aggregate including recycled concrete aggregate.

2.3. Recycled Aggregate and Recycled Concrete Aggregate

2.3.1. Recycled aggregates must conform to certain standard for optimum engineering use; clean, hard, strong, durable particles free of absorbed chemical, coating of clay, and other fine materials in amounts that could affect hydration and bond of the cement paste. For this project, it does not include recycled glass aggregate, recycled plastic, tiles, clayware, brick etc.

2.3.2. Recycled concrete aggregate principally comprising crushed concrete consisting of natural aggregate coated with cement paste residue and/or lumps of lean cement paste residue or natural aggregate.

2.3.2.1. The term of recycled aggregate used in this project includes recycled concrete aggregate. Properties of the recycled aggregate can be tested in accordance with requirement set in BS812 to investigate suitability of the aggregate in new concrete.

2.4. Recycled Aggregate Concrete

2.4.1. Recycled aggregate concrete is concrete product produced with recycled aggregate to replace part or whole of natural aggregate.

3. PROPERTIES OF AGGREGATE AFFECTING PERFORMANCE OF CONCRETE

3.1. Concrete consists mainly of cement, aggregate and water. Therefore, in order to investigate the effect of using recycled aggregate for produce of concrete, it is necessary to understand the relationship between property of aggregate and performance of concrete products. In general, their relationship can be summarized in Table 3.1 and elaborated in the following sections.

Concrete Property	Relevant Aggregate Property
Durability	
Resistance to freezing and thawing	Soundness, porosity, pore structure, permeability, tensile strength, texture and structure, clay minerals
Resistance to wetting and drying	Pore structure, modulus of elasticity
Abrasion resistance	Hardness
Alkali-aggregate reaction	Presence of particular siliceous constituents
Strength	Strength, surface texture, cleanness, particle shape, maximums size
Shrinkage and creep	Modulus of elasticity, particle shape, grading, cleanness, maximum size, clay minerals
Unit weight	Specific gravity, particle shape, grading, maximum size
Modulus of elasticity	Modulus of elasticity, Poisson's ratio

Table 3.1 Properties of Concrete Influenced by Aggregate Properties (Sidney and J Francis, 1981)

3.2. The grading and maximum aggregate size will affect relative aggregate proportions, water cement ratio, workability, and durability of concrete..

3.3. The freeze-thaw resistance of an aggregate, especially important in exterior concrete in cold climate, is related to its porosity, absorption, permeability, and pore structure.

3.4. Abrasion resistance is essential when the aggregate is to be used in concrete subject to abrasion, as in heavy-duty floors or pavements. Low abrasion resistance of an aggregate may increase the quantity of fines in the concrete during mixing and consequently may increase the water requirement.

3.5. Aggregates with certain forms of silica or carbonates will react with alkalies in cement, particularly when the concrete is subject to a warm, moist environment. It is called Alkali-aggregate reaction. The reaction generally forms reaction products that can cause excessive expansion and cracking or popouts in concrete and affect the durability of concrete.

3.6. The properties of the aggregate are tested in order to ensure that the aggregate used in the test comply with the specification laid down in the General

Specification for Civil Engineering works.

4. METHODOLOGY

4.1. Design Mix

4.1.1. The methodology adopted involved mainly laboratory evaluation of concrete with and without recycled concrete aggregate. Samples were prepared in accordance with grade 35/20 concrete. The proposed water cement ratio was 0.48. Portland cement to BS 12 : 1996 was used for making of the specimens.

4.1.2. Six concrete mixes were prepared as shown in Table 4.1

	Normal Aggregate source : Pioneer (Anderson Road)			Recycled Aggregate Source : C&D Material Recycling Facility at Tuen Mun Area 38			Cement Brand: Emerald	PFA Brand : Lamsonite	Target Slump (mm)	Adjusted Weight of Water (kg)
	Weight (kg)			Weight (kg)			Weight (kg)	Weight (kg)		
	20mm	10mm	Fines	20mm	10mm	Fines	Cement	PFA		
1 : - 0% PFA & 0% R.A.	32.450	18.700	43.725	---	---	---	22.000	---	100	10.805
5 : - 35% PFA 0% R.A.	32.450	18.700	43.725	---	---	---	14.300	7.700	70	10.805
2 : - 0% PFA 20% R.A.	25.960	14.960	34.980	6.490	3.740	8.745	22.000	---	100	11.106
6 : - 35% PFA 20% R.A.	25.960	14.960	34.980	6.490	3.740	8.745	14.300	7.700	70	11.106
4 : - 0% PFA 100% R.A.	---	---	---	32.450	18.700	43.725	22.000	---	100	12.307
8 : - 35% PFA 100% R.A.	---	---	---	32.450	18.700	43.725	14.300	7.700	70	12.307

Table 4.1:- Design Mix for volume of 0.055 m^3

4.1.3. For each mix, 8 nos. of 100mm concrete cube, 16 nos. of 100mm diameter concrete cylinder, 1 no. of 150mm diameter concrete cylinder and 6 nos. of concrete prim (75mm x 75mm x 285mm) was cast for testing.

4.1.4. Recycled Aggregate used in this study were obtained from Temporary Recycling Facility at Tuen Mun Area 38. Recycled aggregates obtained in this facility are mainly recycled concrete aggregate. Due to the fact that it is composed of natural stone coated with hydrated cement paste, recycled concrete aggregate has a higher loss of soundness and a higher abrasion loss than natural aggregate.

The cement paste is weaker and more prone to degradation the nature stone.

4.1.5. To ensure the quality of the recycled aggregate, the sample have been collected and tested bi-monthly from February to November 2003. The aggregate was assessed in accordance with BS 812 in order to confirm the particle size and other properties are complied with the standard for making concrete. Accelerated mortar bar test to RILEM AAR-2 was also carried out to ensure that AAR of the recycled aggregate are within acceptable limits.

4.1.6. With reference to previous research findings, it was identified that workability of fresh concrete would decrease with using recycled concrete aggregate. Therefore additive was used to produce flowing concrete at the same water cement ratio without loss in strength.

4.2. Laboratory Testing

4.2.1. The following tests were performed on the specimens for each concrete mix:

i) Slump test : - 2 times per each mix

ii) Cube strength : -

   a) on 7 days; (2 nos.)

   b) on 28 days. (4 nos. and 2 nos. as spare or test at 56 days)

iii) Cylinder strength : -

   a) on 7 days; (2 nos.)

   b) on 28 days. (2 nos.)

iv) Young Modulus of Elasticity : - to determine E-value of 150mm diameter concrete cylinder for testing of at 28 days (2 nos.)

v) Chloride penetration test : - use accelerated bulk diffusion and profile grinding to study chloride penetration resistance with 28-day and 56-day immersion after 28-day maturity; (allow 3 cylinders for each immersion period, profile grinding at 2mm/layer with total of 8 layers from surface, the value taken will be the average of three test results)

vi) Water absorption test : - to check the initial surface absorption according to BS 1881: Part 208: 1996 and capillary absorption of concrete according to BS 1217: 1997; require 3 cylinders for each water absorption test.

vii) Shrinkage test : - to monitor the changes in the length of prisms at 28, 56, 90, 180 days under controlled environment at 20 ± 2°C and R.H. at 60 ± 5%. By use of 4 prisms for measurement and allow 2 nos. for spares, the value taken will be the average of four test results.

viii) Accelerated Mortar Bar Test – Testing to the standard of RILEM AAR-2 in order to monitor the properties of recycled concrete aggregate with regard to potential AAR reaction. Recycled concrete aggregate will be collected and tested bimonthly.

5. TEST RESULTS

5.1. RILEM AAR 2 test

5.1.1. Five batch of sample were collected bimonthly from February 2003 to November 2003. The samples were tested in accordance with RILEM AAR 2 to determine the AAR potential of the recycled concrete aggregate. To increase the reliability of the results, the test was carried out by two competent technical officers individually. The results were tabulated in Table 5.1

Sampling Date	Operator A		Operator B	
	Specimen No.	%	Specimen No.	%
24/02/03	a	0.085	D	0.087
	b	0.086	E	0.087
	c	0.087	F	0.085
	Average	**0.09**		**0.09**
14/05/03	a	0.095	5D	0.110
	b	0.094	5E	0.107
	c	0.097	5F	0.108
	Average	**0.10**		**0.11**
22/07/03	a	0.055	Ril7A	0.059
	b	0.055	Ril7B	0.058
	c	0.058	Ril7C	0.059
	Average	**0.06**		**0.06**
28/09/03	a	0.079	Ril9A	0.094
	b	0.076	Ril9B	0.103
	c	0.078	Ril9C	0.100
	Average	**0.08**		**0.10**
28/11/03	a	0.114	Ril11A	0.122
	b	0.119	Ril11B	0.124
	c	0.113	Ril11C	0.123
	Average	**0.12**		**0.12**

Table 5.1:- Average Expansion of Mortar Bar (16 Days after casting)

5.2. Slump Test

5.2.1. Two slump tests were carried out for each design mix. The results are shows in Table 5.2.

Mix No.	Date of Mixing	Admixture Brand: Daracem 100 Volume of Admixture used(ml)	Time of Water Added	Measured Slump (mm)	Temp. of Fresh Concrete (°C)
1 : - 0% PFA & 0% R.A.	23/07/2003	139.5	09:55	75	25.3
				80	
				Av: 80	
5 : - 35% PFA & 0% R.A.	23/07/2003	173.3	14:30	65	25.1
				60	
				Av: 65	
2 : - 0% PFA & 20% R.A.	31/07/2003	129.5	09:55	80	24.3
				90	
				Av: 85	
6 : - 35% PFA & 20% R.A.	31/07/2003	163.3	14:40	60	25.2
				65	
				Av: 65	
4 : - 0% PFA & 100% R.A.	07/08/2003	269.5	10:00	30	25.6
				30	
				Av: 30	
8 : - 35% PFA & 100% R.A.	07/08/2003	173.3	14:35	45	23.9
				40	
				Av: 45	

Table 5.2: - Summary of Mixing Records

5.2.2. It was found that for replacement of 20% recycled aggregate concrete, there was no noticeable decrease in slump. They were about 80mm and 65mm for concrete without PFA and with 35% PFA respectively. However, for replacement of 100%, the measured slumps decreased significantly to below 45mm. Even though admixture was added no improvement in slump was measured.

5.3. Compressive Strength

5.3.1. Cube and Cylinder samples were prepared for test of compressive strength of the concrete. The results were tabulated in the Table 5.3

Mix No.	Cube Strength (Mpa)				Cylinder Compressive Strength (Mpa)			
	Specimen No.	7 days	Specimen No.	28 days	Specimen No.	7 days	Specimen No.	28 days
1 : - 0% PFA &	M1CU07-A	48.5	M1CU28-A	56.7	M1CY07-A	47.7	M1CY28-A	55.5
0% R.A.	M1CU07-B	48.5	M1CU28-B	56.8	M1CY07-B	48.1	M1CY28-B	57
	Mean	*48.5*	M1CU28-C	56.2	*Mean*	*47.9*		
			M1CU28-D	55.4				
			Mean	*56.3*			*Mean*	*56.25*
5 : - 35% PFA	M5CU07-A	28.2	M5CU28-A	43.7	M5CY07-A	30	M5CY28-A	44
0% R.A.	M5CU07-B	27.4	M5CU28-B	43.2	M5CY07-B	29.8	M5CY28-B	45.5
	Mean	*27.8*	M5CU28-C	45.2	*Mean*	*29.9*	*Mean*	*44.75*
			M5CU28-D	44.0				
			Mean	*44.0*				
2: - 0% PFA	M2CU07-A	41.9	M2CU28-A	51.7	M2CY07-A	47.1	M2CY28-A	56
20% R.A.	M2CU07-B	41.6	M2CU28-B	51.1	M2CY07-B	47.7	M2CY28-B	54.5
	Mean	*41.75*	M2CU28-C	51.0	*Mean*	*47.4*	*Mean*	*55.25*
			M2CU28-D	51.9				
			Mean	*51.4*				
6 : - 35% PFA	M6CU07-A	29.6	M6CU28-A	43.1	M6CY07-A	31.7	M6CY28-A	44.5
20% R.A.	M6CU07-B	29.8	M6CU28-B	43.1	M6CY07-B	30.9	M6CY28-B	45.5
	Mean	*29.7*	M6CU28-C	43.8	*Mean*	*31.3*	*Mean*	*45*
			M6CU28-D	44.6				
			Mean	*43.7*				
4 : - 0% PFA	M4CU07-A	41.5	M4CU28-A	48.9	M4CY07-A	42	M4CY28-A	49.5
100% R.A.	M4CU07-B	41.3	M4CU28-B	46.6	M4CY07-B	42.8	M4CY28-B	47
	Mean	*41.4*	M4CU28-C	48.1	*Mean*	*42.4*	*Mean*	*48.25*
			M4CU28-D	47.3				
			Mean	*47.7*				
8 : - 35% PFA	M8CU07-A	24	M8CU28-A	38.6	M8CY07-A	25.6	M8CY28-A	39.5
100% R.A.	M8CU07-B	24.9	M8CU28-B	36.7	M8CY07-B	25.8	M8CY28-B	38.5
	Mean	*24.45*	M8CU28-C	37.6	*Mean*	*25.7*	*Mean*	*39*
			M8CU28-D	38.2				
			Mean	*37.8*				

Table 5.3 : - Compressive Strength Test

5.3.2. As shown in the Table 5.3, for concrete with 20% RA replacement, the strength of concrete cube of without PFA was about 10% lower than concrete with normal aggregate. Nevertheless, based on the strength of cylinders and concrete with 35% PFA, there is no noticeable change. For 100% RA replacement, it was found that the strength of the concrete would be about 13-15% lower than normal concrete.

5.4. Young Modulus of Elasticity

5.4.1. Young modules of elasticity of the sample was measured and the result were listed in the following table.

Mix No.	Specimen No.	Static Modulus of Elasticity in Compression (Mpa)	Mean (Mpa)
1 : - 0% PFA & 0% R.A.	M1EV-A	24500	
	M1EV-B	25000	24750
5 : - 35% PFA 0% R.A.	M5EV-A	23500	
	M5EV-B	24000	23750
2: - 0% PFA 20% R.A.	M2EV-A	26000	
	M2EV-B	25500	25750
6 : - 35% PFA 20% R.A.	M6EV-A	23500	
	M6EV-B	23500	23500
4 : - 0% PFA 100% R.A.	M4EV-A	22500	
	M4EV-B	22500	22500
8 : - 35% PFA 100% R.A.	M8EV-A	22500	
	M8EV-B	22000	22250

Table 5.4 : - Static Modulus of Elasticity in Compression

5.4.2. For 20% RA replacement, there was no noticeable change in modulus of elasticity in compression. However, for 100% replacement, the modulus of elasticity could decrease by around 6% and 9 % for concrete with and without PFA respectively.

samples.

Mix No.	Initial Surface Absorption (ml/(m^2s))							Capillary Absorption (mg/mm2)		
	Specimen No.	10-minute		30-minute		1 hour				
		interval	mean	interval	Mean	interval	mean	Specimen No.		mean
1 : - 0% PFA & 0% R.A.	M1ABIN-A	0.11		0.08		0.06		M1ABCA-A	0.3	
	M1ABIN-B	0.11	*0.12*	0.07	*0.07*	0.06	*0.06*	M1ABCA-B	0.3	*0.3*
	M1ABIN-C	0.13		0.07		0.06		M1ABCA-C	0.3	
5 : - 35% PFA 0% R.A.	M5ABIN-A	0.12		0.07		0.06		M5ABCA-A	0.4	
	M5ABIN-B	0.11	*0.12*	0.06	*0.07*	0.05	*0.06*	M5ABCA-B	0.3	*0.4*
	M5ABIN-C	0.12		0.08		0.07		M5ABCA-C	0.4	
2: - 0% PFA 20% R.A.	M2ABIN-A	0.07		0.04		0.04		M2ABCA-A	0.3	
	M2ABIN-B	0.16	*0.10*	0.11	*0.06*	0.09	*0.05*	M2ABCA-B	0.3	*0.3*
	M2ABIN-C	0.06		0.04		0.03		M2ABCA-C	0.4	
6 : - 35% PFA 20% R.A.	M6ABIN-A	0.13		0.08		0.06		M6ABCA-A	0.4	
	M6ABIN-B	0.19	*0.18*	0.12	*0.11*	0.09	*0.08*	M6ABCA-B	0.4	*0.4*
	M6ABIN-C	0.21		0.13		0.10		M6ABCA-C	0.4	
4 : - 0% PFA 100% R.A.	M4ABIN-A	0.33		0.20		0.17		M4ABCA-A	0.8	
	M4ABIN-B	0.38	*0.32*	0.23	*0.20*	0.17	*0.15*	M4ABCA-B	0.6	*0.7*
	M4ABIN-C	0.24		0.16		0.12		M4ABCA-C	0.6	
8 : - 35% PFA 100% R.A.	M8ABIN-A	0.32		0.20		0.15		M8ABCA-A	0.6	
	M8ABIN-B	0.24	*0.27*	0.15	*0.17*	0.11	*0.13*	M8ABCA-B	0.6	*0.6*
	M8ABIN-C	0.25		0.16		0.12		M8ABCA-C	0.6	

Table 5.7 : Initial Surface Absorption and Capillary Absorption

5.5.2. Based on the above result, it was clearly found that in comparing with concrete with original aggregate, absorption of the specimens with 20% recycled aggregate replacement dose not have noticeable increase in absorption. However, with 100% recycled aggregate replacement, absorption will increase significantly.

5.6. Shrinkage test

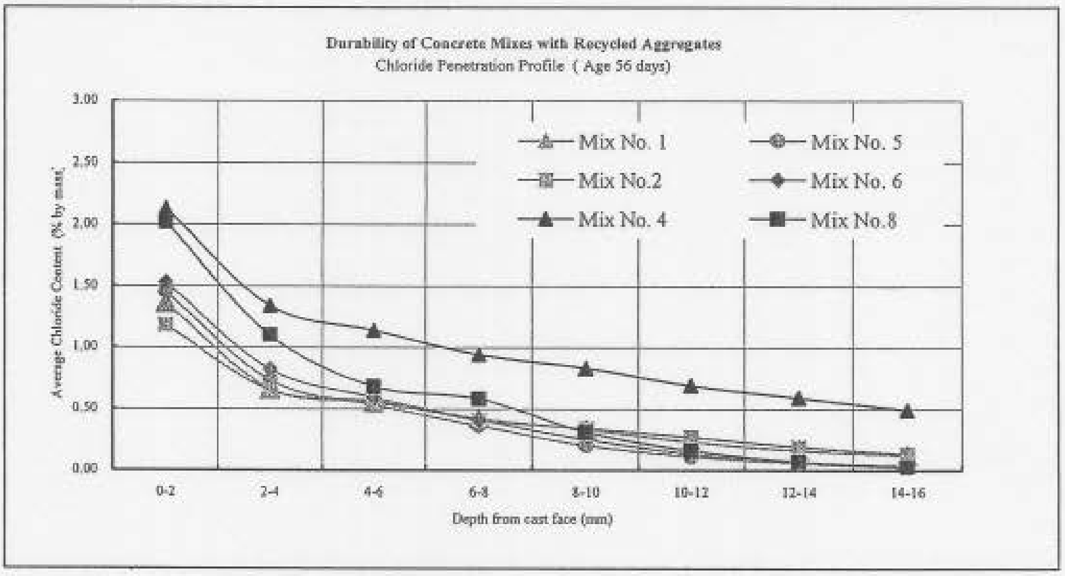
5.6.1.

Mix No.	Length Change of Concrete Prism (%)								
	Specimen No.	28 days	Mean	56 days	Mean	90 days	Mean	180 days	Mean
1 : - 0% PFA &	M1PR-A	0.010		-0.041		-0.057		-0.080	
0% R.A.	M1PR-B	0.008		-0.042		-0.058		-0.081	
	M1PR-C	0.006	*0.008*	-0.040	*-0.040*	-0.052	*-0.055*	-0.077	*-0.078*
	M1PR-D	0.005		-0.041		-0.056		-0.077	
	M1PR-E	0.010		-0.038		-0.050		-0.074	
5 : - 35% PFA	M5PR-A	-0.027		-0.076		-0.091		-0.110	
0% R.A.	M5PR-B	-0.025		-0.069		-0.083		-0.098	
	M5PR-C	-0.006	*-0.013*	-0.052	*-0.058*	-0.066	*-0.073*	-0.081	*-0.089*
	M5PR-D	-0.006		-0.047		-0.064		-0.079	
	M5PR-E	-0.001		-0.047		-0.060		-0.076	
2: - 0% PFA	M2PR-A	0.007		-0.037		-0.052		-0.076	
20% R.A.	M2PR-B	0.006		-0.037		-0.053		-0.076	
	M2PR-C	0.006	*0.007*	-0.037	*-0.036*	-0.053	*-0.052*	-0.076	*-0.075*
	M2PR-D	0.006		-0.036		-0.052		-0.073	
	M2PR-E	0.009		-0.032		-0.050		-0.073	
6 : - 35% PFA	M6PR-A	0.005		-0.042		-0.054		-0.071	
20% R.A.	M6PR-B	0.001		-0.042		-0.055		-0.073	
	M6PR-C	0.001	*0.003*	-0.043	*-0.042*	-0.057	*-0.054*	-0.077	*-0.073*
	M6PR-D	0.001		-0.040		-0.050		-0.069	
	M6PR-E	0.005		-0.043		-0.056		-0.077	
4 : - 0% PFA	M4PR-A	0.004		-0.064		-0.081		-0.108	
100% R.A.	M4PR-B	0.005		-0.065		-0.082		-0.109	
	M4PR-C	0.003	*0.005*	-0.065	*-0.064*	-0.082	*-0.081*	-0.109	*-0.109*
	M4PR-D	0.006		-0.063		-0.080		-0.108	
	M4PR-E	0.006		-0.064		-0.082		-0.111	
8 : - 35% PFA	M8PR-A	0.004		-0.046		-0.064		-0.086	
100% R.A.	M8PR-B	0.004		-0.048		-0.064		-0.089	
	M8PR-C	0.005	*0.005*	-0.047	*-0.047*	-0.064	*-0.063*	-0.085	*-0.086*
	M8PR-D	0.004		-0.048		-0.063		-0.086	
	M8PR-E	0.006		-0.048		-0.060		-0.082	

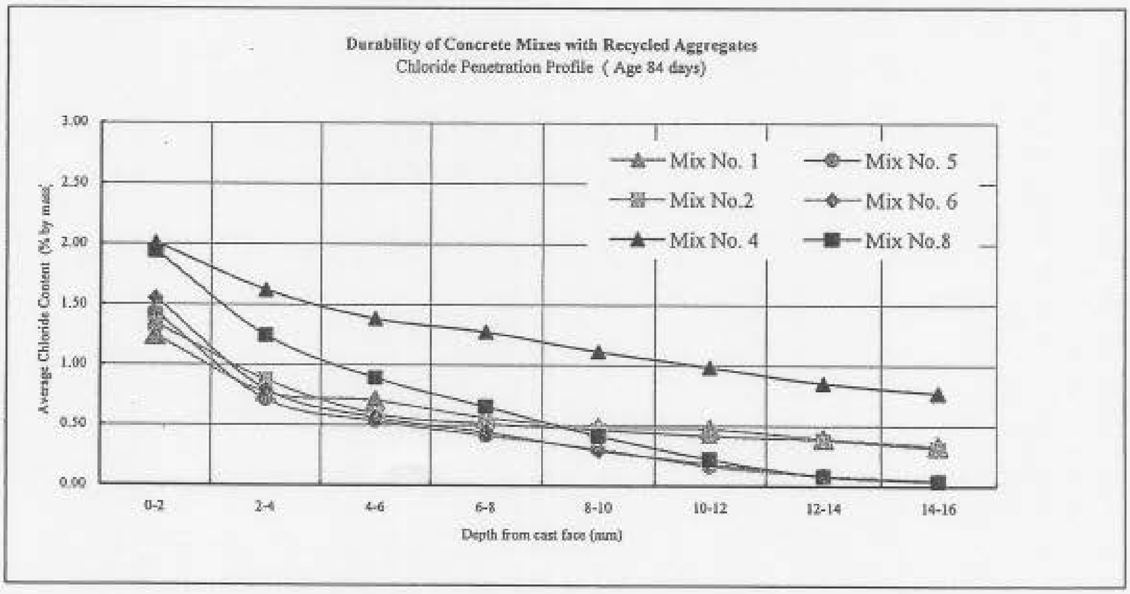
Table 5.8 : - Results of Shrinkage Test

5.6.2. The results of shrinkage test show that there were no noticeable change in the shrinkage no matter 20% or 100% recycled aggregate replacement.

5.7.1. Chloride penetration tests were carried out with 28-day and 56-day immersion after 28-day maturity. The chloride penetration profiles were presented on the following plots.



Plot 5.7.1 : - Chloride Penetration Test (Age 56 Days)



Plot 5.7.2 : - Chloride Penetration Test (Age 84 Days)

5.7.2. The results show that there was no noticeable change of chloride penetration in between concrete with 20% RA or without RA no matter they were with or without PFA. However, the concrete with 100% RA replacement and without PFA, the chloride penetration will be significantly increased. The increase can be depressed by add PFA as indicated by the result of Mix No 8.

6. SUMMARY AND OBSERVATIONS

6.1. Limited tests carried out in this study did not show noticeable difference in the properties of concrete when 20% of the aggregate in the concrete was recycled aggregate

6.2. The properties of concrete with 100% recycled aggregate were inferior to concrete with normal aggregate. Chloride penetration was significantly higher. This higher penetration was not observed in concrete of 100% recycled aggregate with 35% PFA