University of Southern Queensland

Faculty of Engineering and Surveying

THE USE OF RECYCLED CONCRETE AGGREGATE IN STRUCTURAL CONCRETE AROUND SOUTH EAST QUEENSLAND

A Dissertation Submitted By

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Abstract

This study aims to develop the best economic solution by use of recycled aggregate in structural concrete to reduce the environmental impact around South East Queensland. Therefore, the objective of this project is to investigate the hardness properties of Recycled Concrete Aggregate including slump, density, compressive strength, tensile strength, modulus of elasticity and drying shrinkage. This is also to determine the durability and permeability, quality and cleanliness that are suitable for application in high strength concrete up to 60MPa compared with 100% natural aggregate from the pits around South East Queensland which is provided from local companies.

To determining the above properties of the recycled aggregate by studying the influence of 100 percent recycled aggregate in concrete. The Laboratory trials were conducted to investigate the possibility of using 100 percent of recycled aggregate (20mm, 14mm and 10mm) with 25 percent of fly ash (low volume of 20% fly ash is minimum requirement by MainRoads specifications) to replace part of the cement in concrete, compared with natural aggregate.

The project has also researched the costs for what is the most economical solution to making recycled aggregate for high quality concrete around South East Queensland by consulting with the local technical specialists and related firms to broadening the RCA use for structural concrete in the concrete industry in Australia.

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Certification

I certify that the ideas, designs and experimental work, results and analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Signature

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Date

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Table of Content

Abstract **2**

Limitations of Use **3**

Certification **4**

Acknowledgments **5**

CHAPTER 1 INTRODUCTION **13**

1.1 Background/Problem Statement 13

1.2 Understanding the application of Recycled Aggregates 14

1.3 Project Aim 16

1.4 Layout of Dissertation 17

Chapter 2 LITERATURE REVIEW OF RECYCLED AGGREGATE **18**

2.1 Literature review of Recycled Aggregate 18
2.1.1 Strengths of Recycled Aggregate Concrete Made Using Field-Demolished Concrete as Aggregate 19
2.1.2 Use of Recycled Concrete Aggregate 19
2.1.3 Behaviour of Construction and Demolition Debris in Base and Subbase Application 20
2.1.4 Improving the workability and strength of silica fume concrete by using silane-treated silica fume 20
2.1.5 Concrete with Recycled materials as Coarse Aggregates: Shrinkage and Creep Behaviour 21
2.1.6 Strength Characteristics of Concrete Made with Recycled Fine Aggregate and Crushed Stone Fines 21
2.1.7 Influence of recycled aggregate quality on concrete properties 22
2.1.8 Some studies on durability of recycled aggregate concrete 22
2.1.9 Use of recycled aggregates in moulded concrete bricks and blocks 23
2.1.10 Influence of Quality of Recycled Fine Aggregate on Properties of Concrete 24
2.1.11 Treatments for the improvement of recycled aggregate 24
2.1.12 Construction and Demolition Waste Recycling Reuse as Aggregate in Concrete Production 25

2.2 Conclusions 25
2.2.1 Fly Ash 26
2.2.2 Silica Fume ASTM C 1240 27
2.2.3 Superplasticizer 28

Chapter 3 PRODUCTION OF RECYCLED AGGREGATE **29**

3.1 Introduction – Case Study of Recycling Queensland 29

3.2 Sources of material for the production of recycled aggregate 30

3.3 Transportation and Collection 33

3.4 The Recycling Plant 35

3.5 The Process of creating recycled aggregate 36
3.5.1 Pre-sorting of source material 36
3.5.2 Primary Crushing Plant 38
3.5.3 Secondary Crushing Plant 38

3.6 Comparison of Recycled Aggregate and Natural Aggregate 43
3.6.1 Particle Surface Texture 44
3.6.2 Quality 44
3.6.3 Particle Density 45
3.6.4 Aggregate Strength 45
3.7 Conclusions 46

Chapter 4 PROPERTIES AND TESTING OF AGGREGATE 50

4.1 Percentage of organic/contaminates 50
4.1.1 Apparatus and Test Procedure of Percentage of organic/contaminates 50
4.1.2 Result and Analysis 51
4.2 Particle Size Distribution of Aggregate (Dry Sieving) Q103B-1996 51
4.2.1 Apparatus and Test Procedure of Particle Size Distribution of Aggregate 51
4.2.2 Result and Analysis 53
4.3 Particle Density and Water Absorption of Coarse Q214B-1996 and Fine Aggregate Q214A-1996 55
4.3.1 Apparatus and Test Procedure of Coarse Aggregate 55
4.3.2 Apparatus and Test Procedure of Fine Aggregate 58
4.3.3 Result and Analysis 62
4.4 Particle shape/Proportional Calliper AS1141.14 64
4.4.1 Apparatus and Test Procedure of Particle shape/Proportional Calliper 64
4.4.2 Result and Analysis 65
4.5 Wet/Dry Strength Variation Q205C-1986 66
4.5.1 Apparatus and Test Procedure of Wet/Dry Strength Variation 66
4.5.2 Result and Analysis 70
4.6 Los Angeles Abrasion AS1141.23 71
4.6.1 Apparatus and Test Procedure of Los Angeles Abrasion 71
4.6.2 Result and Analysis 74
4.7 Determination of Soundness of Sodium Sulphate AS1141.24 75
4.7.1 Apparatus and Test Procedure of Sodium Sulphate Soundness 75
4.7.2 Result and Analysis 77
4.8 Organic impurities other than sugar AS1141.34 78
4.8.1 Apparatus and Test Procedure of Organic impurities other than sugar 78
4.8.2 Result and Analysis 79
4.9 Conclusions 80

Chapter 5 EXPERIMENTAL METHODOLOGY 81

5.1 Mix Design of RCA 81
5.2 Mixing and moulding of Concrete (Mixes) AS1012.02 83
5.2.1 Workability Tests of Fresh Concrete and Slump Test AS1012.03 86
5.2.1.1 Apparatus and Test Procedure of Slump Test 86
5.2.2 Method for making and curing concrete AS1012.8.1 90
5.2.2.1 Apparatus and Test Procedure 90
5.3 Part I Testing on Hardened Properties of Concrete Cylinders Specimens 94
5.3.1 Compressive Strength of Concrete AS1012.1 94
5.3.1.1 Apparatus and Test Procedure of Compressive Strength of Concrete 94
5.3.2 Indirect Tensile Test AS1012.10 99
5.3.2.1 Apparatus and Test Procedure of Indirect Tensile Test 99
5.3.3 Determination of the modulus of rupture AS1012.11-2000 103
5.3.3.1 Apparatus and Test Procedure of modulus of rupture 103
5.4 Part II Testing for Durability and Permeability of Concrete 105

5.4.1 Drying Shrinkage of Concrete of Prism AS1012.13 ... 105
5.4.1.1 Apparatus and Test Procedure of Drying Shrinkage of Concrete Test ... 105
5.4.2 Determination of the Static chord Modulus of elasticity of concrete specimens AS1012.17-1997 ... 108
5.4.2.1 Apparatus and Test Procedure of Modulus of elasticity of concrete specimens ... 108
5.4.3 Determination of water absorption and apparent volume of permeable voids in hardened concrete AS 1012.21 ... 113
5.4.3.1 Apparatus and Test Procedure of water absorption and apparent volume of permeable voids in hardened concrete ... 113
5.4.4 Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration ATM 1202 – 97 ... 116
5.4.4.1 Apparatus and Test Procedure of Chloride Ion Penetration ... 116

Chapter 6 TEST RESULTS AND DISCUSSION ... 118

6.1 Introduction ... 118

6.2 Slump Test Result and Analysis ... 119

6.3 Compressive strength Test Result and Analysis ... 120

6.4 Indirect Tensile Test Result and Analysis ... 122

6.5 Modulus of Rupture Test Result and Analysis ... 124

6.6 Drying Shrinkage of Concrete ... 125

6.7 Static chord Modulus of Elasticity Test Result and Analysis ... 126

6.8 Water Absorption and apparent volume of permeable voids Test Results and Analysis ... 127

6.9 Rapid Chloride Permeability Test Results and Analysis ... 129

6.10 Summary of Recycled Concrete ... 131

6.11 Conclusions ... 132
6.11.1 The advantages of using recycled aggregate in structural concrete ... 132
6.11.2 The disadvantages of using recycled aggregate in structural concrete ... 133

Chapter 7 SUMMARY AND RECOMMENDATIONS ... 134

7.1 Conclusion ... 134

7.2 Achievement of Objectives ... 135

7.3 Recommendations for Further Studies ... 136

References ... 137

Appendix ... 141

Project Specification ... 141

Assessment of Consequential Effects ... 143

Project Methodology ... 144

Safety Issues ... 144

Resource Planning ... 146

List of Figures

Figure 1.1 Recycled Aggregates from the local Recycled Company
Figure 3.1 Recycling Plant
Figure 3.2 Mixture of Crushed materials
Figure 3.3 Truck
Figure 3.4 Hook Bin
Figure 3.5 Pre-sorting
Figure 3.6 Picker Station
Figure 3.7 Magnet
Figure 3.8 Air Knives
Figure 3.9 Wind Sifter
Figure 3.10 Screening
Figure 3.11 Pricelist of recycled aggregate
Figure 3.12 Sized 20mm recycled aggregate
Figure 3.13 Sized 14mm recycled aggregate
Figure 3.14 Sized 5mm recycled aggregate
Figure 3.15 Crusher & Dust recycled aggregate
Figure 3.16 Sized 20mm Natural Aggregate and Recycled Aggregate
Figure 4.1 Sieve and Balance
Table 4.2 Particle Size Distribution
Figure 4.3 Particle Size Distribution
Figure 4.4 Thermometer
Figure 4.5 Thermostatically Controlled Oven
Figure 4.6 Equipment for Water absorption
Figure 4.7 Constant temperature room
Figure 4.8 Result of Particle Density and Water absorption
Figure 4.9 Test Cylinder
Figure 4.10 Result of Wet/Dry Strength Variation
Figure 4.11 Los Angeles machine
Figure 4.12 Sample Dividers
Table 5.1 Proportional of mix design
Figure 5.2 Pan Mixer at Herston Laboratory
Figure 5.3 Mixing Procedure
Figure 5.4 Typical mould for slump test
Figure 5.5 Mould, Rod, Scoop and Baseplate
Figure 5.6 Lime-saturated water tank

Figure 5.7 Cylinder Mould
Figure 5.8 Drying Shrinkage Mould
Figure 5.9 Compressive Test Machine
Figure 5.10 Sulphate Mixture
Figure 5.11 Capping Plate
Figure 5.12 Measuring Equipment
Figure 5.13 Dimension of Typical Jig
Figure 5.14 Typical Jig
Figure 5.15 Jib Marker
Figure 5.16 Flexure Testing Apparatus
Figure 5.17 Drying Room
Figure 5.18 Comparator
Figure 5.19 Compressometer
Figure 5.20 Applied Voltage Cell
Figure 6.1 Result of Slump Test
Figure 6.2 Compressive Strength Result
Figure 6.3 7-days age Cylinder
Figure 6.4 Indirect Tensile Strength Result
Figure 6.5 7-days age Cylinder broken by Indirect Tensile Strength
Figure 6.6 Flexure Strength Result
Table 6.7 Result of Drying Shrinkage
Figure 6.8 Result of Drying Shrinkage
Figure 6.9 Result of Young Modulus
Table 6.10 Water Absorption and apparent Volume of Permeable Voids
Figure 6.11 Water Absorption and apparent Volume of Permeable Voids
Figure 6.12 Result of Rapid Chloride Permeability
Table 6.13 Result of Rapid Chloride Permeability
Figure 6.14 Summary of Result of Recycled Concrete

CHAPTER 1

INTRODUCTION

1.1 Background/Problem Statement

Aggregate is one of the most vitally important materials in use for concrete production as it profoundly influences concrete properties and performance. Regarding aggregate usage in concrete, a conservative estimate is that at least 4.5 billion tons of concrete aggregates per year are consumed worldwide. This figure is assumed to represent total aggregate production, including usage in concrete and road base. Aggregate usage in concrete constitutes perhaps between 25 and 35 per cent of the total aggregate production. The sheer bulk of global aggregate usage is staggering.

The above inevitably impacts on the environment due to the great huge quantity of general and construction waste materials or from building demolition sites generated in developed countries. The research conducted for the Industry Commission Report indicated that about 3 million tons of waste aggregate has been created in the Australia alone. The disposal of all this waste has become a harsh social and environmental problem. This is a large burden on the world's natural resources and an increasingly expensive problem for solid waste management. Therefore, a possible alternative aggregate method to overcome this issue may be using recycled concrete aggregates instead of natural aggregate in construction tasks. This solution not only can help to conserve and extend natural resources but also can reduce the cost of waste treatment and the demand on landfill sites for disposing the waste.

In this project, the other most important issue is to determine the best solution to make the recycled concrete aggregate economical for most infrastructure tasks especially in structural concrete around South East Queensland.

1.2 Understanding the application of Recycled Aggregates

The recycled concrete aggregate shown in Figure 1.1 can be defined as crushed concrete composed of aggregate fragments coated with cement paste or cement mortar from the demolition of the old structures or pavements that has been processed to produce aggregates suitable for use in new concrete. The processing, as with many natural aggregates, generally involves crushing, grading and washing. This removes contaminant materials such as reinforcing steel, remnants of formwork, gypsum board, and other foreign materials. The resulting coarse aggregate is then suitable for use in concrete. The fine aggregate, however, generally contains a considerable amount of old cement paste and mortar. This tends to increase the drying shrinkage and creep properties of the new concrete, as well as leading to problems with unworkable mix and strength. Therefore, many transportation departments have found that using 100% coarse recycled aggregate but with only about 10% to 20% recycled fines works well.

Regarding the results of most of the previous research that has been done so far, the application of Recycled Aggregate is mostly currently in low quality/strength concrete, for example, pavement base and slab rather than used in structural concrete. The most common application of Recycled Concrete Aggregate is the use in concrete sub-base in road construction, bank protection, noise barriers and embankments, many types of general bulk fills and fill materials for drainage structures.

After the removal of contaminants through selective demolition, screening, and/or air separation and size reduction in a crusher to aggregate sizes, crushed concrete can be used as new concrete for pavements, shoulders, median barriers, sidewalks, curbs and gutters, and bridge foundations; structural grade concrete; soil-cement pavement bases; moulded concrete bricks and blocks; bituminous concrete etc. However, there is an example of recycled concrete being used for part of the structural slabs in a high-rise building in Japan but there was no too much detail available on this project.

According to research that has been conducted in Australia, current use of recycled aggregates is still only around 7% of road construction material in South Australia. Victoria Road also use recycled aggregate for their road base construction projects in Victoria but MainRoads in Queensland does not currently.

Figure 1.1 Recycled Aggregates from the local Recycled Company

1.3 Project Aim

The aim of this project is to determine the characteristic strength and durability properties of 100% recycled aggregate used in structural concrete, compared with natural aggregate, as well as to find the most economical solution and quality of the recycled concrete aggregate around the South East Queensland to reduce the environmental impact.

The scope of this project:

- Review and research the literature relating to the use of recycled aggregate.
- Research all the important issues of production in recycled concrete aggregate in South East Queensland. For example, quality and cleanliness, consistency of each batch of concrete using recycled aggregate.
- Testing as required of recycled aggregate used in structural concrete according to the Queensland and Australian Standard. Use the obtained results to develop out the best mix proportion of the Laboratory trial specimens.
- Construct the concrete cylinder specimens to Australian Standard and MainRoads specification with 100 percent recycled aggregate.
- Investigation and laboratory testing on high strength concrete up to 60MPa with 100 percent of recycled aggregates with or without silica fume.
- Analysis of the test results and evaluated the possible use in the construction tasks.
- Findings and recommendation from this study for further research in this particular area.

1.4 Layout of Dissertation

This dissertation is structured in the following format.

• Chapter 2 provides a review of relevant literature of recycled concrete aggregate. This chapter also discuss any issues from previous investigations and research that has been done for recycled aggregate around the world.

• Chapter 3 concerns the sources of the concrete. The method and cost of the transport and collection of the concrete to be recycled. The procedure for the production of good quality recycled concrete aggregate including the level of screening required. The type and capacity of the plant used for crushing. The treatment of "contamination" components of the demolition waste streams, such as plastics, plaster or gypsum, wood and metals has to be separately addressed. Removal and cleaning of reinforcing steel to be re-sold as scrap.

• Chapter 4 provides all the significant testing for recycled aggregate including shape, grading, strength, elastics modulus, chemical and physical properties. The chapter then explores the determining what concrete mix design according the particle size grading and particle shape.

• Chapter 5 describes the experimental methodology carried out in order to obtain the required data and to achieve the result of high strength concrete.

• Chapter 6 discusses the results and analysis of all laboratory data obtained from the experimental procedures. What are the advantages and disadvantages by using the Recycled Aggregate in structural concrete?

• Chapter 7 contains the conclusions of the research to indicate the overall economics of recycling costs compared with conventional concrete and recommendations on further work.

Chapter 2

Literature review of Recycled Aggregate

2.1 Literature review of Recycled Aggregate

The applications of recycled aggregate in highway construction as a road base materials are very board and have been in use for almost 100 years. There has been much research based on the use of recycled aggregate that has been carried out all around the world. The research on recycled aggregate that has been carried out indicated that the successful application of crushed aggregate in concrete can be achieved. This successful research has been achieved in many countries, in particular in Europe; United States; Japan and China. This chapter presents literature reviews on the effects of various factors on the recycled aggregate from research from those countries.

The major objective of most of the experiments or research on recycled aggregate is to find out the results in the strength characteristic area and what is the best method to achieve high strength concrete with recycled aggregate.

2.1.1 Strengths of Recycled Aggregate Concrete Made Using Field-Demolished Concrete as Aggregate

Tavakoli M. (1996) studied the compressive; splitting tensile and flexural strengths of 100% recycled coarse aggregate concrete and 100% natural sand to compare them with normal concrete made of natural crushed stone. The water-cement ratio was 0.3 and 0.4 in the concrete mix design. The test result shows the compressive, tensile and flexural strengths of RCA are little higher than the natural aggregate at the same size of 25.4mm at 28-day specimen. This indicates that if the compressive strength of the original concrete that is being recycled is higher than that of the control concrete, then the recycled aggregate concrete can also be made to achieve higher compressive strength than the control concrete. The results also indicates increase L.A. abrasion loss and water absorption capacity of recycled aggregates, which partly refect the increased amount of water, adhering to the original stone aggregate, generally lead to reduced compressive strength of recycled aggregate concrete.

2.1.2 Use of Recycled Concrete Aggregate

Dhir et al. (1998) studied the effect of the cleanliness and percentage of the replacement of RCA. They found out that the degree of cleanliness of aggregate has significantly affected on the results of the properties of both the plastic and hardened concrete. The workability and compressive strengths both were lower than the quarried aggregate from 17% to 78% depending on the percentage of replacement of RCA. The results also indicated recycled aggregate has very high air content.

2.1.3 Behaviour of Construction and Demolition Debris in Base and Subbase Application

Pappjr et al (1998) studied using recycled aggregates in Base and Subbase applications. They found that recycled concrete yielded higher resilient modulus than the dense graded aggregate currently used. Furthermore, the results have been shown that recycled concrete have less permanent deformation than dense graded aggregate. They concluded that recycled concrete could be a valuable alternative to natural materials for base and subbase applications.

2.1.4 Improving the workability and strength of silica fume concrete by using silane-treated silica fume

Xu and Chung (1999) studied improving the workability and strength by using 15 percent silica fume by weight of cement. Silane-treated silica fume acted as a superplasticizer to enhance wet ability of Silica Fume by water to improve the workability. It also improved the bond between silica fume and cement and increased density of the mortar. It causes the tensile strength to increase by 31% and the compressive strength to increase by 27% up to 78 MPa, relative to the obtained without treatment. It is possible that this could be used to increase the workability and the strength of recycled concrete aggregate mixes.

2.1.5 Concrete with Recycled materials as Coarse Aggregates: Shrinkage and Creep Behaviour

Tawrwe et al. (1999) compared limestone aggregate with concrete rubble. They found the concrete rubble had a very high water absorption compared to the limestone aggregate (0.74% against 6.83% of dry mass). Furthermore the porous aggregate absorbed water slowly in some tests. For example, it was difficult to determine accurately the amount of water that had to be added to obtain suitable workability. The critical shrinkage of the limestone aggregate concrete was higher than the concrete rubble, but after a year the shrinkage was greater for the concrete rubble based aggregate.

2.1.6 Strength Characteristics of Concrete Made with Recycled Fine Aggregate and Crushed Stone Fines

Kishoreet et al. (1999) studied 27 concrete mixes to determine whether natural aggregates could be replaced by alternative recycled aggregates. Large amounts of demolition of old structures have generated millions of tonnes of demolition debris. Disposal of this waste is an environmental problem. Crushing plants create crusher fines which could be used to replace natural sands. This is what the paper looks at and found out the mixes resulted in low workability in terms of slump and compaction factor values. Loss of workability was rapid in the first fifteen minutes, after which the workability did not change significantly. In addition, strength reduction was high in concrete which were 50 percent or more of the aggregate had been replaced. However this meant that up to 50 percent of the natural sand could be replaced with recycled aggregate.

2.1.7 Influence of recycled aggregate quality on concrete properties

Sanchez de Juan et al. (2000) studied what is the maximum percentage, from 20% to 100%, replacement of recycled aggregate in concrete. The results showed that the compressive strength of recycled concrete is lower than that of a control concrete with equal water/cement ratio and same cement content. Recycled concretes with a percentage of recycled coarse aggregate lower than 50% show decreases in the range 5-10%, while for concretes with 100% recycled aggregates, decreases ranged from 10-15%. Experimental results also indicated that properties of conventional concretes and recycled concretes with same compressive strength when less than 20% of recycled coarse aggregate are used. The exception being modulus of elasticity was decreased until 10% can be found in recycled concretes. When the percentage of recycled aggregate is lower than 50%, tensile strength and drying shrinkage of recycled concrete is similar to conventional concrete with same compressive strength. As a result of the testing, all properties of concrete with a 100% of recycled coarse aggregate are affected.

2.1.8 Some studies on durability of recycled aggregate concrete

Mandal et al. (2002) studied the durability of recycled aggregate concrete and found that recycled aggregate had less durability than natural aggregate. However, when 10 percent replacement of cement by fly ash was used with recycled aggregate, the durability observed was increased. It significantly improved the compressive strength up to 46.5MPa, reduced shrinkage and increased durability to a level comparable to natural aggregate. Therefore, the results of this study provide a strong support for the feasibility of using recycled aggregate instead of natural aggregate for the production of concrete.

2.1.9 Use of recycled aggregates in moulded concrete bricks and blocks

Poon et al. (2002) developed a technique to produce concrete bricks and paving blocks from recycled aggregates. The test result showed that replacing natural aggregate by 25% to 50% had little effect on the compressive strength, but higher levels of replacement reduced the compressive strength. The transverse strength increased as the percentage of recycled aggregate increased. The concrete paving blocks with a 28-day compressive strength of at least 49MPa can be produced without the incorporation of fly ash by using up to 100% recycled aggregate. According to the study, recycled aggregate has been used in structural engineering. For example, a viaduct and marine loch in the Netherlands in 1998 and an office building in England in 1999. The project in the Netherlands had shown that 20 percent of the coarse aggregate was replaced by recycled aggregate. The project also indicated even there are some disadvantage of recycled aggregate such as being too weak, more porous and that it has a very higher value of water absorption. However, the study showed that these weaknesses could be avoided by using mechanized moulded concrete bricks. The workability also could be improved by poring the mix into the mould. Therefore, the performance of the bricks and blocks was also satisfactory in the shrinkage and skid resistance tests.

2.1.10 Influence of Quality of Recycled Fine Aggregate on Properties of Concrete

Fumoto et al. (2002) studied replacing river sand with recycled aggregate. They found that recycled fine aggregate had larger surface areas, and that the particle shape was much worse compared with that of ordinary river sand. The studied also showed that air content could have a very strong influence on the slump. There was less air content because of the larger surface areas of the recycled fine aggregate. They also found that recycled aggregate has higher water absorption which has a strong effect on concrete strength. However, the researchers found that, by adding superplasticizer of 0.6% of cement content, the compressive strength to a similar level as natural aggregate.

2.1.11 Treatments for the improvement of recycled aggregate

Katz (2004) stated two methods to improve the quality of the recycled aggregates. The superplasticizer (1% weight of silica fume) was added to the solution of 10L of water and 1 kg raw silica fume to ensure proper dispersion of silica fume particles. After the silica fume impregnation, the SF treatment seems to improve significantly the compressive strength up to 51MPa at ranged from 23% to 33% at 7 days of the recycled aggregate concrete. Ultrasonic cleaning of the recycled aggregate to remove the loose particles and improve the bond between the new cement paste and the recycled aggregate, which, in turn, increased 7% of strength.

2.1.12 Construction and Demolition Waste Recycling Reuse as Aggregate in Concrete Production

Limbachiya (2004) studied the properties of recycled aggregate compared with natural aggregates and found out the density of RCA is typically 4-8% lower and water absorption 2-6 times higher. The results showed that a reduction in slump value with increasing RCA concrete mix. The results also slowed that up to 30% coarse RCA has no effect on the standard concrete cube strength but thereafter a gradual reduction with increasing RCA content occurs. This means that some adjustment is necessary of the water/cement ratio to achieve the equivalent strength with high proportions of RCA.

2.2 Conclusions

According to the above Literature Review, I found out that the source, Particle size distribution, cleanliness/quality, water-cement ratio all have effects on the strength of recycled aggregate. I also realised the higher compressive strength may be achieved by using certain amount of fly ash, silica fume and superplasticizer. Therefore, I proposed to improve the strength, durability and permeability of Recycled concrete in this study by adding certain amount of fly ash, dense silica fume, and superplasticizer provided from Boral in south-east Queensland.

2.2.1 Fly Ash

Fly ash is the mineral residue produced by burning coal and is captured from the power plant's exhaust gases and collected for use. Fly ash particles are almost totally spherical in shape ("ball bearing"), allowing them to flow and blend freely in mixtures. Therefore, it can be improve workability without increasing water requirements.

Fly ash also improves the pump-ability of concrete by making it more cohesive and less prone to segregation. It generally provides increased concrete strength gain for much longer periods than mixes with Portland cement only. The other major reason to use fly ash in concrete is the increased life cycle expectancy and increase in durability associated with its use. During the hydration process, fly ash chemically reacts with the calcium hydroxide forming calcium silicate hydrate and calcium aluminate, which reduces the risk of leaching calcium hydroxide and concrete's permeability. Fly ash also improves the permeability of concrete by lowering the water-to-cement ratio, which reduces the volume of capillary pores remaining in the mass. The spherical shape of fly ash particles improves the consolidation of concrete, which also reduces permeability.

Other benefits of fly ash in concrete that include resistance to corrosion of concrete reinforcement, attack from alkali-silica reaction, sulphate attack, acids, and salt attacks.

2.2.2 Silica Fume ASTM C 1240

Silica fume is a by-product of producing silicon metal or ferrosilicon alloys. The raw materials are quartz, coal and woodchips. The smoke from the furnace operation is collected and sold as silica fume. Silica fume consists primarily of amorphous (non-crystalline) silicon dioxide (SiO_2). The individual particles are extremely small, approximately 1/100th the size of an average cement particle (refer to Silica Fume Association). One of most beneficial uses for silica fume in concrete is a very reactive pozzolan because of its fine particles, large surface area and the high SiO_2 content.

Concrete containing silica fume can have very high strength, with compressive strength in excess of 15000 psi (refer to Silica Fume Association). Using Silica fume in concrete can make the concrete be very durable because with low water content it is highly resistant to penetration by chloride ions. Using silica fume, high-strength concrete is a very economical material for carrying vertical loads in high-rise structures and new bridges.

2.2.3 Superplasticizer

A superplasticizer is one of a class of admixtures called water-reducers that are used to lower the mix water requirement of concrete and are capable of reducing water contents by about 30 per cent. Superplasticizer has a powerful dispersion effect on both binding agents and fine aggregate particles. The polymer is surface-active and absorbed on the surface of the materials. It forms a lubricating film between the particles lowering the internal cohesion between the components and gives better consistency. This makes it possible to reduce the water content, increasing the early strength and reducing the setting time. It is also extreme flow-ability, water reduction, high strength rapid solubilization and quality consistent product concrete.

The basic advantages of superplasticizers include as follows:

- High workability of concrete, resulting in easy placement without reduction in cement content and strength.
- High strength concrete with normal workability but lower water content.
- Concrete mix with less cement but normal strength and workability.

Chapter 3

Production of Recycled Aggregate

3.1 Introduction – Case Study of Recycling Queensland

Recycling of concrete is a relatively simple process similar to crushing natural aggregate. It involves breaking, removing and crushing existing concrete into a material with a specified size and quality. For a good quality product it is essential to separate out different types of material before it enters the crusher. A high level of cleanliness of the material is essential to creating a quality end product that can be reused.

For this chapter, it would be refer to Recycling Queensland and their Brisbane plant in Figure 3.1 as an example in the production of recycled aggregate.

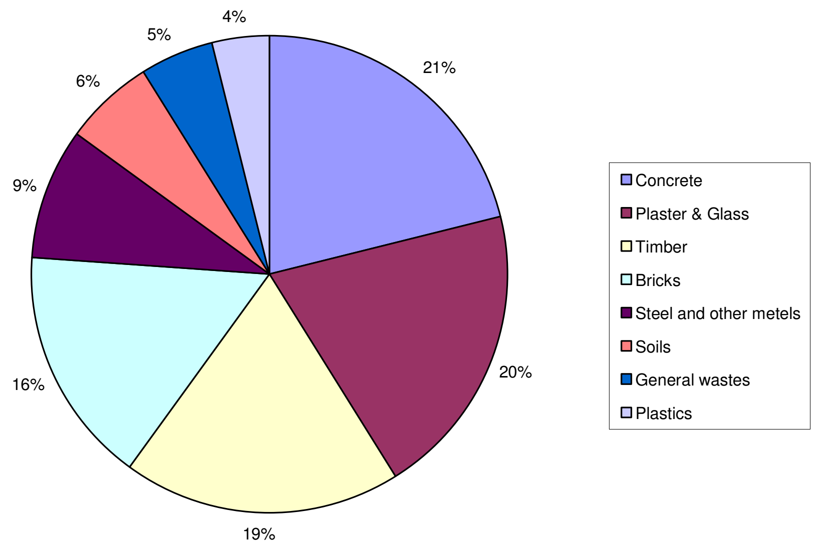
Figure 3.1 Recycling Plant

(Source: Recycling Queensland)

3.2 Sources of material for the production of recycled aggregate

A major source of concrete comes from the demolition of building or general demolition construction. The materials supplied to the local recycling plant will generally come from within a 20-30 kilometre radius of the recycling plant.

The source of concrete will be mixed with other materials. For example, according to research conducted by Recycling Queensland, the composition of demolition material (refer to Figure 3.2) will generally be a mix of 21% concrete, 20% plaster-card board-paper-glass mix, 19% timber, 16% bricks, 9% steel and other metals, 6% soil, 5% general wastes, and 4% plastics.



Mixture of crushed material from a building construction according to QLD Recycling

Figure 3.2 Mixture of Crushed materials

The quality of the recycled aggregate will depend on how clean the material is when it enters the crusher. Cleanliness refers to how much foreign material is removed, leaving only concrete.

The ideal place to begin the separation of materials is at the demolition site itself. Fixtures, such as wood, windows, plumbing and electrical wiring can be removed and recycled separately before the reminder of the structure is demolished.

The common demolition method is by using an impact hammer. Other equipment used to demolish buildings and other sites and remove the concrete from the site includes the following;

- A diesel pile-driving hammer can be mounted on a motor grader. This is used for pavement. The diesel pile- driving hammer will be placed into the pavement in a 30mm grid pattern.

- A rhino, horn, tooth or ripper equipped hydraulic excavator can then be used to remove any steel reinforcement from the cement pavement.
- For building, a mechanical hydraulic crusher with a long boom arm can break the concrete and steel reinforcement. This is particularly useful for buildings which are dangerous for people to enter because the long boom arm system allows access from a distance.
- A wrecking ball can be used. This will demolish the building through impacts by the wrecking ball which is suspended from a crawler crane.

Finally, implosion can be used. The structure should already be weakened and the fixtures and fittings all removed. The building should be in a husk-like state. Explosives are then placed throughout the building. When the explosives are detonated, the building should collapse inwards. This method is not widely used in Australia due to safety considerations.

The quality of concrete is an important cost consideration. Currently, Queensland Recycling charges approximately $6.0 a tonne for clean concrete (raw concrete) and up to $20.0 a tonne for dirty concrete (mixed materials) to tip off into the plant.

3.3 Transportation and Collection

After the demolishing of the structure in question, the material will be transported to the recycling plant for processing. The material can be transported via various methods. The four most common methods include the use of the roll-off containers, large dump body trailers, closed box trailers and covered containers.

Most clients of Recycling Queensland use trucks as pictured (refer to Figure 3.3) below. The material is deposited into hook bins. Casual clients, such as home renovators, will usually only fill one or two hook bins (refer to Figure 3.4).

Upon arrival at the plant, the trucks will be weighed and a price will be calculated based on the quality and weight of the delivered materials.

Figure 3.3 Truck

(Source: Recycling Queensland)

Figure 3.4 Hook bin

(Source: Recycling Queensland)

3.4 The Recycling Plant

The recycling plant referred to in this study is the Recycling Queensland recycling plant, located in north side of Brisbane and near the Gateway Motorway. That gives easy access to the plant from the North and South for the greater South East Queensland region.

The recycling plant can recycle materials such as concrete, masonry, steel, timber, soil and glass into consumable finished products.

According to the Brendon Fennelly (Operations Co-ordinator of Queensland Recycling), the recycling plant normally produced about 6000 tonnes aggregate per a week, including 20-25% of this as 20mm sized aggregate.

3.5 The Process of creating recycled aggregate

3.5.1 Pre-sorting of source material

The first stage upon arrival at the recycling plant is the pre-sorting (refer to Figure 3.5) of the material. All demolition materials will go through a primary sorting system to first separate steel, timber, Gyprock, chipboard, fibre board, paper, light bulk, concrete and heavy fines. All dirty concrete would be tip off truck and passes through the Erin Screen.

Figure 3.5 Pre-sorting

3.5.2 Primary Crushing Plant

The material will then enter the primary crushing plant.

The first stage of this is the Pulveriser Excavator. This machine will crush the concrete into half meter round pieces. The Pulveriser Excavator is a type of impacted mill crusher.

The soil is then further 'scalped' away. Scalping occurs with a 25mm scalping screen to remove soil and clay balls from the broken concrete.

The material then enters the primary crusher which will break it down to 100mm to 150mm sized aggregate. This crusher is usually a jaw crusher.

3.5.3 Secondary Crushing Plant

As the crushed material leaves the primary crushing plant, the material will pass through a picker station (refer to Figure 3.6). Personnel standing here will attempt to remove any remaining wood, reinforced steel, plastics and other large objects.

Figure 3.6 Picker Station

(Source: Recycling Queensland)

The material will then pass through magnets (refer to Figure 3.7). This electromagnetic separation removes any remaining reinforced steel and other metallic scrap. According to the information provided by Queensland Recycling, the reinforced steel is usually sold to the Sim Metal company for shipping to overseas to such destinations as Japan and Korea because it is not common to sell recycled steel in Australia for high premiums.

Figure 3.7 Magnets

There are two other methods of screening or separating the material to create clean aggregate. They are Dry Separation and Wet Separation.

Wet separation involves the material passing through an aquamator, in which low density foreign materials are removed by water jets and the use of a float/sink tank. This does produce a very clean aggregate. This method is not currently in use at the Recycling Queensland plant in Brisbane.

Dry Separation involves the use of blowing air to remove lighter particles from the heavier concrete material. This method is in use at the Recycling Queensland plant. Air Knifes (refer to Figure 3.8) and Wind shifters (refer to Figure 3.9) are both is use at the Recycling Queensland plant. Recycled aggregate is generally 'blown' at least twice and usually three times.

Figure 3.8 Air Knives

Figure 3.9 Wind Sifter

(Source: Recycling Queensland)

The cleaned material then enters the secondary crushing plant. This is a core crusher at the Recycling Queensland plant. The crusher can be set to a certain size and the crushed material is then passed through screens (refer to Figure 3.10). There are multiple screens which sort the aggregate into multiple sizes. Aggregate, which is too large, would go back to the electromagnetic separation and cycles through the Air Knives and back into the secondary crusher.

Figure 3.10 Screening

(Source: Recycling Queensland)

3.6 Comparison of Recycled Aggregate and Natural Aggregate

It is important to be aware of the difference between recycled aggregate and natural aggregate (refer to Figure 3.16). This way the differences can be taken into account and possibly mitigated when using recycled aggregate in concrete mixes.

Figure 3.16 Sized 20mm Natural Aggregate (left hand side) and Recycled Aggregate (right hand side)

3.6.1 Particle Surface Texture

Recycled Aggregate tends to be rougher. Recycled aggregate has a large surface area. Natural Aggregate tends to be smoother and more rounded. This greatly affects the quality of the cement. Natural aggregates can compact more closely; resulting is stronger compressive strength and lower water absorption. Recycled aggregates rougher shape means that the particles do not fit as compactly. There are more voids, which results in greater water absorption and cause weaker between the bonding.

The particle surface texture can also affect water content and mix water requirements in a mix. Therefore has effect on the workability in the mix.

3.6.2 Quality

The quality of recycled Aggregate can be very inconsistent because it will depend on the source material's physical and chemical properties. Natural aggregate is much more consistent due to its uniform source.

This variable quality factor can make recycled aggregate difficult to work with. Even in the review literature, many researchers discovered vastly different results from what should have been similar mixes. This could potentially make mix design in a difficult process.

The other significant concern is what level of chloride content of recycled aggregates if the material will be used in reinforced concrete. Therefore, there is a chloride content of recycled concrete in the 56-day age specimen which has been done in this studied (refer to chapter 5.4.4).

3.6.3 Particle Density

The density of Recycled Aggregate is about 17% lower than natural aggregate in the experiments conducted as part of this project. This is due to the relatively porous nature of residual mortar and cement paste or particles adhering to the surface of original natural aggregate to reduce the density due to the less dense nature of the mortar. Particle density influences concrete density in both the plastic and hardened states.

3.6.4 Aggregate Strength

The strength of an aggregate is rarely tested and generally does not influence the strength of conventional concrete as much as the strength of the paste and the paste-aggregate bond. However, aggregate strength does become important in high strength concrete. Concrete produced with 100% recycled aggregate has 80% to 90% of the strength comparable with natural aggregate concrete.

While the natural aggregate contained within the recycled aggregate will still have its original strength, the mortar will of course not, affecting the overall strength of the recycled aggregate. Furthermore, the mortar attached to the aggregate particle can reduce the overall paste aggregate strength of the final product.

Normally, the strength of the aggregate could be determined by using the Wet/Dry strength variation method. The experiment had shown that strength of recycled aggregate is lower than natural aggregate. This may lead to a negative effect on the final compressive strength of concrete produced with recycled aggregate.

3.7 Conclusions

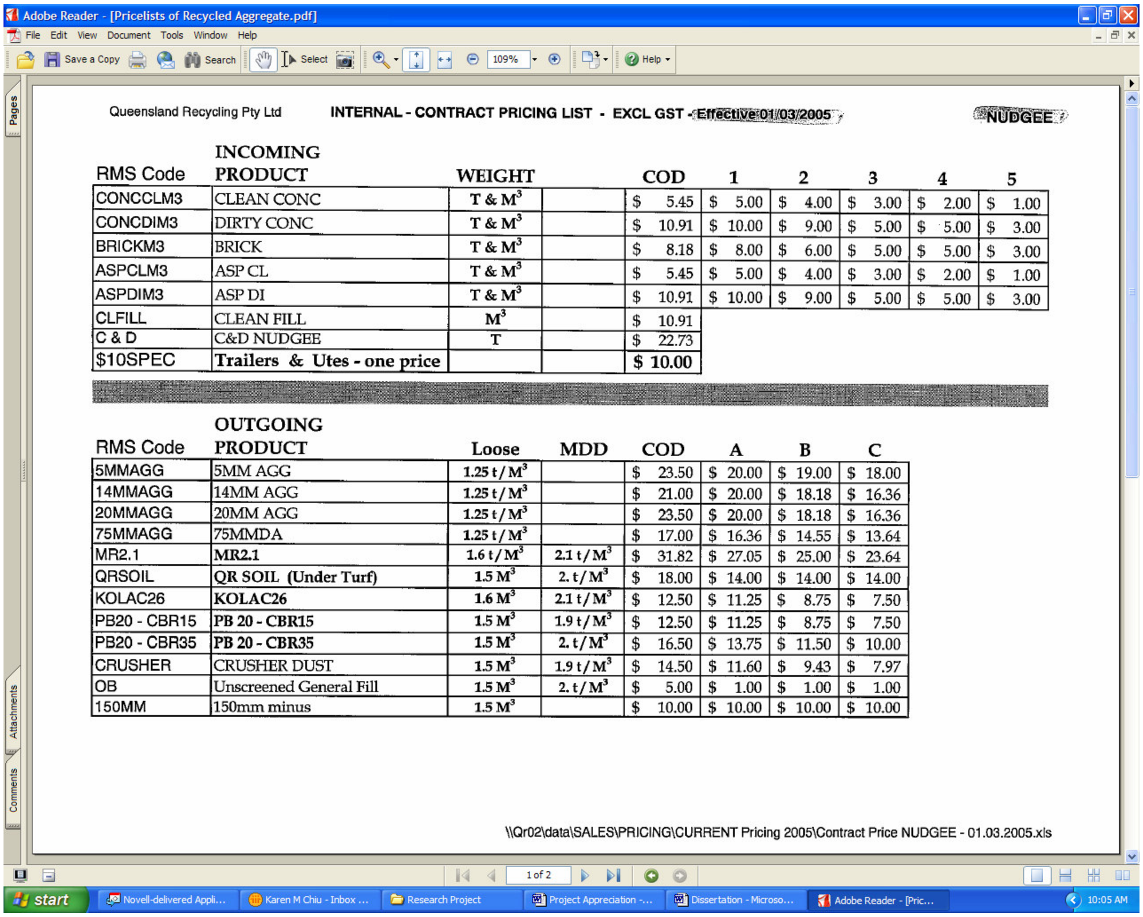
The final product will be separated by the screens into separate sized aggregates. This sorted product is then stored in a stockpile. This stockpile must be kept clean from contamination from foreign materials. Queensland Recycling has stated that their recycled aggregate is 99% clean.

There are four sizes of stockpiled at the Queensland Recycling plant.

- Recycled Aggregate sized 3.5mm or less is called crusher dust (refer to Figure 3.15). It is generally considered too fine for use to make new concrete. Crusher dust has an increased water demand and any chemical contamination from the demolition material is likely to be concentrated in it.
- Recycled aggregate sized 3.5mm to 7mm is known as 5mm aggregate (refer to Figure 3.14).
- Recycled aggregate sized 7mm to 14mm is known as 14mm aggregate (refer to Figure 3.13).
- Recycled aggregate sized greater than14mm is known as 20mm aggregate (refer to Figure 3.12).

Crusher dust is generally used in slab or fills. Coarse aggregate is sold to plumbers for drains. In Victoria, recycled coarse aggregate is being used in road pavement design according to the information provided by Queensland Recycling.

The Queensland Recycling plant normally has about 7,000 tonnes of 20mm aggregate, 500 tonnes of 14mm and 5mm aggregate and 15,000 tonnes of crusher dust in stock. Detail price referring to the following Figure 3.11.



Queensland Recycling Pty Ltd INTERNAL - CONTRACT PRICING LIST - EXCL GST - Effective 01/03/2005 NUDGEE

RMS Code	INCOMING PRODUCT	WEIGHT		COD	1	2	3	4	5
CONCCLM3	CLEAN CONC	T & M^3		$ 5.45	$ 5.00	$ 4.00	$ 3.00	$ 2.00	$ 1.00
CONCDIM3	DIRTY CONC	T & M^3		$ 10.91	$ 10.00	$ 9.00	$ 5.00	$ 5.00	$ 3.00
BRICKM3	BRICK	T & M^3		$ 8.18	$ 8.00	$ 6.00	$ 5.00	$ 5.00	$ 3.00
ASPCLM3	ASP CL	T & M^3		$ 5.45	$ 5.00	$ 4.00	$ 3.00	$ 2.00	$ 1.00
ASPDIM3	ASP DI	T & M^3		$ 10.91	$ 10.00	$ 9.00	$ 5.00	$ 5.00	$ 3.00
CLFILL	CLEAN FILL	M^3		$ 10.91					
C & D	C&D NUDGEE	T		$ 22.73					
$10SPEC	Trailers & Utes - one price			$ 10.00					

RMS Code	OUTGOING PRODUCT	Loose	MDD	COD	A	B	C
5MMAGG	5MM AGG	1.25 t / M^3		$ 23.50	$ 20.00	$ 19.00	$ 18.00
14MMAGG	14MM AGG	1.25 t / M^3		$ 21.00	$ 20.00	$ 18.18	$ 16.36
20MMAGG	20MM AGG	1.25 t / M^3		$ 23.50	$ 20.00	$ 18.18	$ 16.36
75MMAGG	75MMDA	1.25 t / M^3		$ 17.00	$ 16.36	$ 14.55	$ 13.64
MR2.1	MR2.1	1.6 t / M^3	2.1 t / M^3	$ 31.82	$ 27.05	$ 25.00	$ 23.64
QRSOIL	QR SOIL (Under Turf)	1.5 M^3	2. t / M^3	$ 18.00	$ 14.00	$ 14.00	$ 14.00
KOLAC26	KOLAC26	1.6 M^3	2.1 t / M^3	$ 12.50	$ 11.25	$ 8.75	$ 7.50
PB20 - CBR15	PB 20 - CBR15	1.5 M^3	1.9 t / M^3	$ 12.50	$ 11.25	$ 8.75	$ 7.50
PB20 - CBR35	PB 20 - CBR35	1.5 M^3	2. t / M^3	$ 16.50	$ 13.75	$ 11.50	$ 10.00
CRUSHER	CRUSHER DUST	1.5 M^3	1.9 t / M^3	$ 14.50	$ 11.60	$ 9.43	$ 7.97
OB	Unscreened General Fill	1.5 M^3	2. t / M^3	$ 5.00	$ 1.00	$ 1.00	$ 1.00
150MM	150mm minus	1.5 M^3		$ 10.00	$ 10.00	$ 10.00	$ 10.00

\\Qr02\data\SALES\PRICING\CURRENT Pricing 2005\Contract Price NUDGEE - 01.03.2005.xls

Figure 3.11 Price list of recycled aggregate

(Source: Queensland Recycling)

Figure 3.12 Sized 20mm recycled aggregate

Figure 3.13 Sized 14mm recycled aggregate

Figure 3.14 Sized 5mm recycled aggregate

Figure 3.15 Crusher & Dust recycled aggregate

Chapter 4

Properties and Testing of Aggregate

Characteristics of Aggregate

4.1 Percentage of organic/contaminates

This method covers the determination of level of organic or contaminates of the recycled aggregate.

4.1.1 Apparatus and Test Procedure of Percentage of organic/contaminates

Apparatus:

- **Balances** with limits of performance for coarse and intermediate fraction, ±5g.

Test Procedure:

1. Record the air-dry mass of the aggregate sample of each fraction in grams.
2. Spread the sample into the big rectangle tray with a smooth flat surface and seek all the organic materials inside the sample by hand.
3. Weigh the mass of the organic materials.
4. Calculate the percentage of organic materials of the total sample.

4.1.2 Result and Analysis

There are only 0.1 percent of contaminants in fraction size of 20mm aggregate such as brick, timber pieces, which means the cleanliness of the recycled aggregate could be acceptable in the first stage according to the Australia Standards.

4.2 Particle Size Distribution of Aggregate (Dry Sieving) Q103B-1996

This method is for determining the particle size distribution of coarse and fine aggregates and filler using a dry sieving technique. For pre-coated aggregate, the method does not require the pre-coated agent to be removed prior to sieving.

4.2.1 Apparatus and Test Procedure of Particle Size Distribution of Aggregate

Apparatus:

- **Balance** of suitable capacity having readability and a limit of performance as detailed in table of Q103B-1996.
- **Sieve** (Figure 4.1) 26.5mm, 19.0mm, 13.2mm, 9.50mm, 6.70mm, 4.75mm, 2.36mm, 1.18mm, 600μm, 300μm, 150μm, 75μm.
- Sieve brushes.
- **Oven** of suitable capacity having a temperature of 105°C to 110°C and complying with AS1141.2.
- Container of suitable size for drying.

Figure 4.1 Sieves and Balance

Test Procedure:

1. Determine the nominal size of the aggregate by assessing the sieve size at which not more than 10 percent of the particles are larger.
2. Prepare the sample as detailed in Test Method Q101 to obtain a test portion which, when dry, will comply with the minimum mass requirements of Table 1 of Q103B-1996.
3. Weigh the container and record its mass.
4. Place the test portion in the container and dry in the oven to constant mass. Record the mass of the container and test portion.
5. Sieve the sub-sample by hand trough the sieves appropriate to the aggregate nominal size as follows, ensuring no sieve is overloaded which is limited to the standard.

6. Agitate the sieve using a lateral and vertical motion accompanied by a slight jarring action to keep the sample moving over the sieve. Hand placing of particles on sieves of aperture 19.0mm and greater is permitted provide they are not forced through the sieve apertures.

7. Continue the agitation until no more than a further 1 percent by mass of residue on any individual sieve will pass that sieve during a further 1 minutes of continuous hand sieving.

8. Weigh the aggregate retained on each sieve and record its mass.

9. Calculate the percent passing each sieve to the nearest 0.1% by using the DATAPRO Laboratory test data processing system of MainRoads.

4.2.2 Result and Analysis

The grading of the recycled aggregate had been shown in Table 4.2 and Figure 4.3 was achieved the grading requirements and limits of deviation according to the table 1 and 2 of AS2758.1-1998. Therefore, the concrete trial mix can be designed to achieve the required compressive strength.

Table 4.2 Particle Size Distribution

A.S. Test Sieve (mm)	20mm SA	10mm SA	20mm RA	14mm RA	5mm RA	C/Dust	20mm RA (3 months after)	14mm RA (3 months after)
26.5	100		100				100	
19	92.6		88	100			92	100
13.2	36	100	24	33			20	100
9.5	2.2	88.3	2.4	1.1	100		1.9	38
4.75	1.6	22.5	1	0.6	61	100	1.2	3.1
2.36	0	0.7	0	0.5	18	82	1	1.7
1.18		0.6		0.4	2.4	62		1.4
0.6				0.1	1.9	46		
0.425				0.1	1.7	32		
0.3				0	1.4	21		
0.15		0.5			1.1	17		
0.075		0.4			0.7	0		
PAN		0			0		0	0

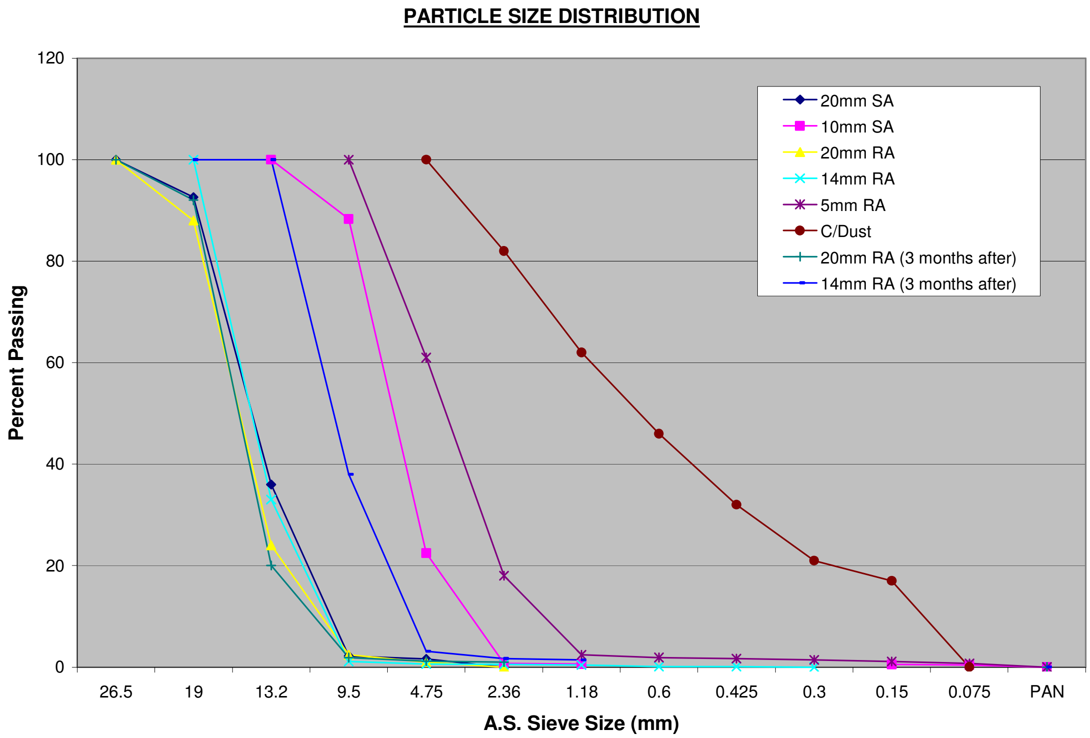


Figure 4.3 Particle Size Distributions

4.3 Particle Density and Water Absorption of Coarse Q214B-1996 and Fine Aggregate Q214A-1996

This method is for the determination of apparent particle density, particle density on a dry basis, particle density on a saturated surface – dry basis and water absorption of the fine fraction of an aggregate. The passing 4.75mm material is tested in this procedure for fine Aggregate.

The retained 4.75mm material is tested in this procedure with volume measurement being made using either below balance or above balance techniques for coarse fraction of an aggregate.

4.3.1 Apparatus and Test Procedure of Coarse Aggregate

Apparatus:

- **Sieve**, 4.75mm complying with AS1152
- **Balance** of suitable capacity, readable to 0.1g and with a limit of performance within the range of ±0.5g.
- **Oven** (Figure 4.5) of suitable capacity having a temperature of 105°C to 110°C and complying with AS1141.2.
- **Absorbent Towel**.
- **Container** of suitable capacity to contain the wire basket.
- **Balance bench**, equipped with a hole for the below balance technique.
- **Wire basket** of suitable capacity to contain the test portion and thin wire to suspend the basket.

- **Thermometer** (Figure 4.4) a partial or total immersion thermometer or other suitable temperature measuring device with a temperature range of 0-50°C and graduated to 1°C or less with an uncertainty of no more than 0.5°C.

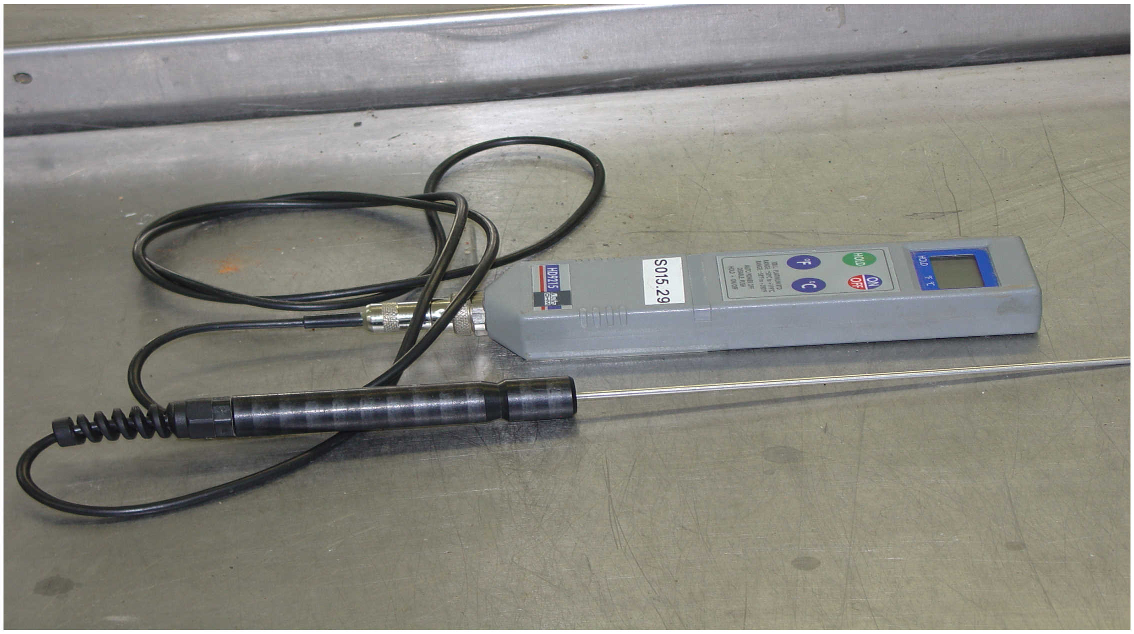


Figure 4.4 Thermometer

Figure 4.5 Thermostatically Controlled Ovens

Test Procedure:

1. Prepare the sample as detailed in Test Method Q101 and screen the material on the 4.75mm sieve to produce a washed coarse fraction sub-sample of at least 5 kg.
2. Place the coarse fraction sub-sample in the oven and dry to a constant mass.
3. Obtain two representative test portions of approximately 2.5kg from the coarse fraction sub-sample.
4. Immerse the test portion in water for at least 24 hours.
5. Remove the aggregate from soaking and transfer the test portion to the basket and agitate the aggregate particle to remove any entrapped air.
6. Weigh the test portion by using below balance technique and record the mass.
7. Place the aggregate one particle deep on a dry clean towel and roll and wipe the particles until all visible films of water have been removed but the surfaces of the aggregate still appear damp.
8. Weigh and record the saturated-dry mass.
9. Then place the aggregate in oven for overnight.
10. Weigh and record the dry mass of aggregate.
11. Calculate apparent particle density, particle densities as required for each portion using the DATAPRO Laboratory test data processing system.

4.3.2 Apparatus and Test Procedure of Fine Aggregate

Apparatus:

- **Sieve**, 4.75mm complying with AS1152
- **Balance** of suitable capacity, readable to 0.01g and with a limit of performance within the range of ±0.05g.
- **Oven** of suitable capacity having a temperature of 105°C to 110°C and complying with AS1141.2.
- **Tray** (Figure 4.6) with a smooth flat surface.
- **Electric Fan Heater** capable of producing a current of warm air.
- **Conical mould** (Figure 4.6) made of any suitable metal, having an internal diameter of 38±3mm at the top and 90±3mm at the bottom and a height of 73±3mm high.
- **Tamping rod** (Figure 4.6) with a mass of approximately 350g having a flat circular tamping face of approximately 25mm diameter.
- **Volumetric flask** of 500mL capacity.
- **Distilled water**.
- **Constant temperature room** (Figure 4.7)
- **Wash bottle**.
- **Thermometer**, a partial or total immersion thermometer with a temperature range of 0-50°C and graduated to 1°C or less with an uncertainty of no more than 0.5°C.

Figure 4.6 Equipment for Water absorption

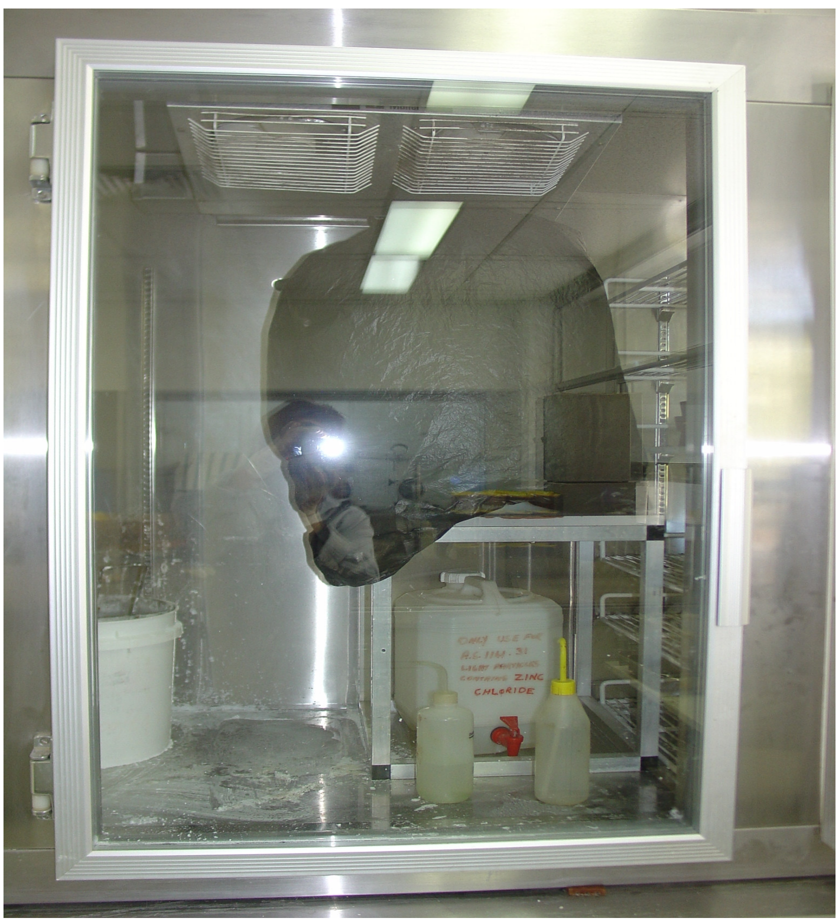


Figure 4.7 Constant temperature rooms

Test Procedure:

1. Prepare the sample as detailed in Test Method Q101 and screen the material on the 4.75mm sieve to produce a fine fraction sub-sample of at least 2 kg.
2. Obtain two representative test portions of approximately 500g from the fine fraction sub-sample.
3. Immerse a test portion in water and allow it to soak for at least 24 hours.
4. At the end of the soaking period carefully drain off the excess water and spread the test portion on the tray.
5. Dry the test portion using a gentle current of warm air, stirring frequently to achieve uniform drying. Continue drying until the aggregate is in a free-flowing condition.
6. Assess the aggregate for the saturated surface-dry condition by loosely filing the mould with aggregate and lightly tamping the top surface with 25 blows of the tamping rod.
7. Lift the mould vertically. If the cone of fine aggregate retains its shape, there is free moisture present and the saturated surface-dry condition has not been reached.
8. Continue drying the test portion and test the aggregate at appropriate intervals as detailed as before until the aggregate slumps on removal of the mould. Slumping of the aggregate indicates that aggregate has reached a saturated surface-dry condition.
9. Immediately obtain a sub-sample of approximately 500g of the surface-dry aggregate and place it in the volumetric flask of know mass.
10. Weigh the flask and saturated surface-dry test portion and record the mass.

11. Fill the flask to just below the 500mL mark with distilled water and roll and shake the flask to eliminate all air bubbles.

12. Place the flask in the constant temperature bath or constant temperature room and allow it to reach an equilibrium temperature. During this time, add distilled water from the wash bottle to bring the water level to the 500mL mark.

13. When the flask and contents have reached an equilibrium temperature, measure and record the temperature of the contents to the nearest 1°C.

14. Add water if necessary in order to maintain the correct level in the flask.

15. Dry the outside of the flask, weigh the flask and contents and record the mass.

16. Remove all the aggregate from the flask and dry the aggregate in the oven to a constant mass.

17. Weigh the dry aggregate and record its mass.

18. Clean the flask and fill it to just below the 500mL mark with distilled water.

19. Place the flask in the constant temperature environment and allow it to reach equilibrium temperature. During this time, add distilled water from the wash bottle to bring the water level to 500mL mark.

20. Dry the outside of the flask then weigh the flask and water and record the mass.

21. Repeat step 4 to 21 for second test portion.

22. Calculate apparent particle density, particle density on a dry basis and particle density on a saturated surface-dry basis, as required for each portion using the DATAPRO Laboratory test data processing system of MainRoads.

4.3.3 Result and Analysis

	20mm SA	10mm SA	20mm RA	14mm RA	5mm RA	C/Dust	20mm RA (3 months after)	14mm RA (3 months after)
Water Absorption	0.82	0.73	5.60	5.41	7.18	8.90	5.08	5.13
Particle Dry Density	2.832	2.857	2.323	2.333	2.275	2.149	2.342	2.345

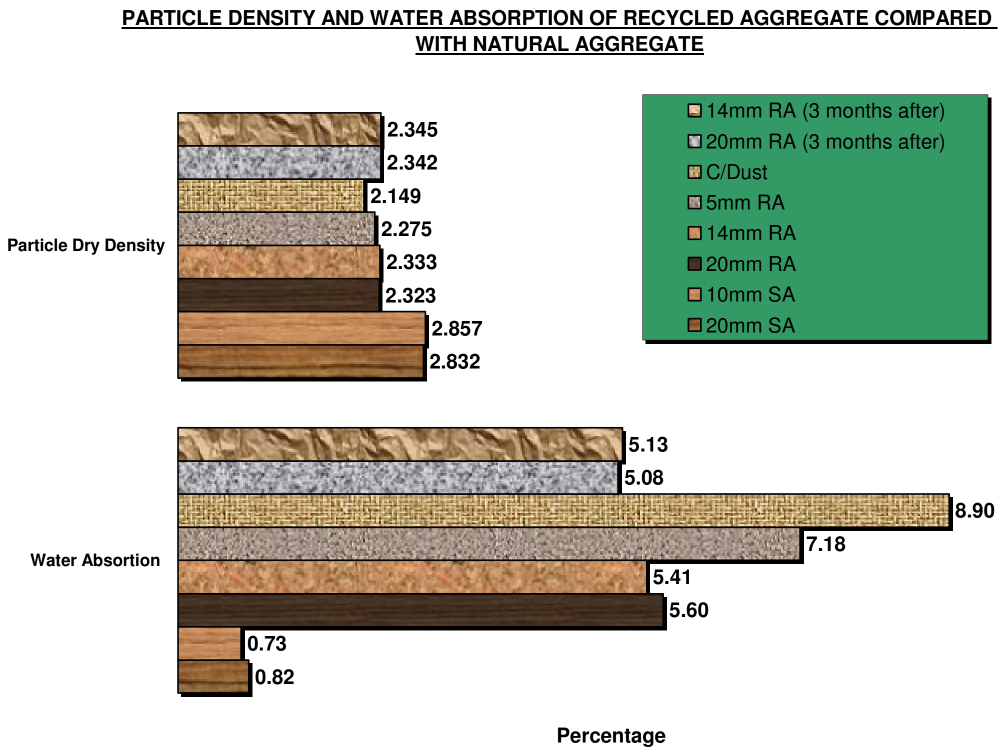


Figure 4.8 Result of Particle Density and Water absorption

From the above figure 4.8, the density in saturated surface dry samples of Recycled Aggregate was 2345kg/m³. As a comparison, natural aggregate would have density around 2857kg/m³. The lower value for the coarse RCA is due to the inclusion of the porous and old mortar.

The results have shown the higher water absorption of 7.2 percent when as the fraction size becomes smaller. Because of small fraction size of recycled aggregate has large surface area than the big one. It has much more mortar attached the surrounding of the recycled aggregate. It indicates that the cleanliness of the recycled aggregate will still need to be judging in the small size fraction.

The percentage of water absorption for the aggregates sized 20mm was 5.6% and sized 14mm was 5.4%. The average permissible water absorption of aggregate should be about 2 percent. However, normal weight aggregates of higher absorption values may be acceptable based on local performance. Therefore, the water absorption of recycled aggregate may be acceptable in this experiment.

The density in saturated surface dry samples of Recycled Aggregate was 2345kg/m^3. As a comparison, natural aggregate would have density around 2857kg/m^3. The lower value for the coarse RCA is due to the inclusion of the porous and old mortar.

4.4 Particle shape/Proportional Calliper AS1141.14

This test is for the determination of the proportion of Flat particle, Elongated particles, Flat and Elongated particles, and misshapen particles in those fractions of a coarse aggregate retained on a 9.50mm A.S. sieve, using proportional callipers.

4.4.1 Apparatus and Test Procedure of Particle shape/Proportional Calliper

Apparatus:

- **Balance** of adequate capacity with a limit of performance not exceeding ±5g.
- **Proportional Calliper** made of steel as shown as below. The fixed post shall be suitable hardened.
- **Thermostatically** controlled **oven** to operate at a temperature of 105°C to 110°C.
- **Sample divider**.
- **Sieve** complying with AS1152 as required.

Test Procedure:

1. Dry the test portion at 105°C to 110°C to constant mass.
2. Separate the test portion into size fraction on the following sieves: 26.5mm, 19.0mm, 13.2mm and 9.50mm.
3. Determine the mass of each size fraction and calculate the grading of the aggregate as received on a percentage passing basic.
4. Calculate the percentage retained in each size fraction.
5. Discard the fraction passing the 9.50mm test sieve.
6. If any size fraction constitutes less than 10 percent of the aggregate as received, it shall be excluded from shape measurement and from subsequent calculations.
7. Recalculation the proportion retained in each remaining size fraction as a percentage of the total amount of the retaining size fractions.

8. Obtain at least 100 particles to be measured by sample division in any size fraction.

9. Determine the mass of these particles and record the number of particles present.

10. Test each of the particles in each of the size fraction prepared for measurement by using the proportional calliper set at the calliper ratio adopted.

11. Sort the particles in each of the size fraction being measured into flat, Elongated, flat and elongated, neither flat nor elongated types.

12. Determine the mass of each of types.

13. Calculate the total percentage of misshapen particles to nearest 1 percent.

4.4.2 Result and Analysis

The total percent misshapen was 0.1 percent of sized 20mm fraction and zero percent of other fraction. According to the specification, the proportion of misshapen particles in coarse aggregate retained on the 9.50mm test sieve shall not exceed 10 percent when determined in accordance with AS1141.14 using a 3:1 ratio.

Therefore, the result had been shown that the particle shape of recycled aggregate can be acceptable. It also indicated that can produce a smooth mix and have good workability.

Strength/Soundness of Aggregate

4.5 Wet/Dry Strength Variation Q205C-1986

This test is for the determination of the strength variation of the aggregate when tested in both the oven dry/dry and saturated surface dry/wet condition.

4.5.1 Apparatus and Test Procedure of Wet/Dry Strength Variation

Apparatus:

- **Test cylinder** (Figure 4.9) plunger and baseplate of 150mm diameter as picture as below.
- Measuring cylinder.
- **Oven**, an oven capable of maintaining a temperature of 105°C to 110°C, preferably with forced draught ventilation.
- **Sieve**, 26.5mm, 19.0mm, 13.2mm, 9.50mm, 4.75mm, 3.35mm and 2.36mm.
- Mallet, rubber mallet with face about 75mm diameter, mass 1100±100g and handle length about 300mm.
- **Compression machine**, a Grade A compression machine of at least 1000kN capacity with a uniform rate of loading, adjustable according to the strength of the material type under test.
- **Balance**, of at least 10kg capacity and accurate to at least 1.0g.
- **Straightedge**, about 300mm long.
- **Absorbent towelling**.

Figure 4.9 Test Cylinder

Test Procedure for dry strength:

1. Obtain the required size fraction by hand sieving.
2. The selected fraction shall be washed on the nominated separating sieve to remove adhering fines.
3. The washed sample shall be dried to constant mass in the oven and allow to cool to room temperature.
4. The mass of the test portion shall be measure by measuring cylinder.
5. Weigh and record the mass of the test portion.
6. Place the test portion into the test cylinder.
7. The assembled test cylinder and test portion shall be placed in position between the platens of the compression testing machine.
8. Force shall be applied at a uniform rate such that the required force shall be applied in 10 minutes. The maximum force applied shall be recorded to the nearest kilo-Newton.

9. The force shall be released and the cylinder removed from the compression machine.
10. Remove the test portion without deliberate breaking of the particles.
11. Sieve the test portion on the nominated separating sieve by hand.
12. Weigh and record the mass of test portion retained on the sieve.
13. Calculate the percentage fines value within the range of 7.5 percent to 12.5 percent produced against the corresponding maximum force.

Test Procedure for wet strength:

1. Obtain the required size fraction by hand sieving.
2. The selected fraction shall be washed on the nominated separating sieve to remove adhering fines.
3. The washed sample shall be dried to constant mass in the oven and allow to cool to room temperature.
4. The mass of the test portion shall be measure by measuring cylinder.
5. Weigh and record the mass of the test portion.
6. The three test portions shall be placed in suitable containers and covered with water at room temperature to a depth of at least 15mm and allowed to soak overnight up to a maximum soaking period of 24 hours.
7. After soaking, one portion shall be removed from the water and allow to drain.
8. After draining, the portion shall be rolled and wiped on absorbent towelling. The process of drying the aggregate shall be continued until all visible films of water have been removed but the surfaces of the particles still appear damp.
9. Place the test portion into the test cylinder.

10. The assembled test cylinder and test portion shall be placed in position between the platens of the compression testing machine.

11. Force shall be applied at a uniform rate such that the required force shall be applied in 10 minutes. The maximum force applied shall be recorded to the nearest kilo-Newton.

12. The force shall be released and the cylinder removed from the compression machine.

13. Remove the test portion without deliberate breaking of the particles.

14. Place the portion to oven capable of maintaining a temperature 105°C to 110°C for dried to constant mass.

15. Sieve the test portion on the nominated separating sieve by hand.

16. Weigh and record the mass of test portion retained on the sieve.

17. Calculate the percentage fines value within the range of 7.5 percent to 12.5 percent produced against the corresponding maximum force.

4.5.2 Result and Analysis

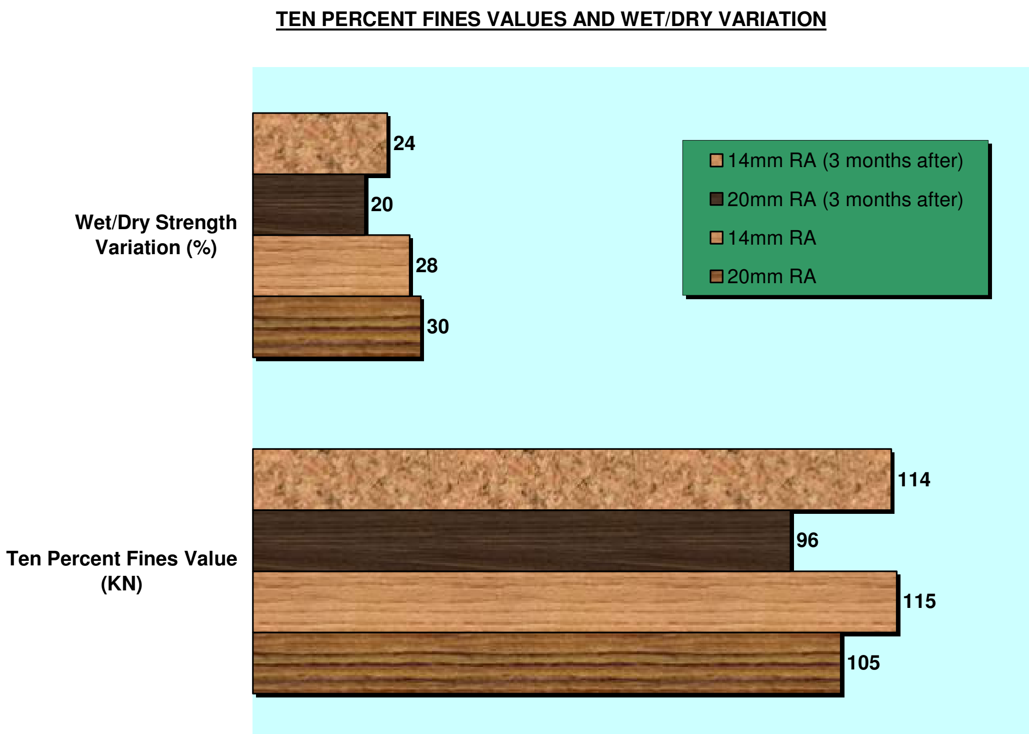


Figure 4.10 Result of Wet/Dry Strength Variation

The result of wet/dry strength variation in Figure 4.10 of the recycled aggregate had been shown between 30 percent of sized 20mm aggregate and 28 percent of sized 14mm fraction.

The permissible wet/dry strength variation is 45 percent for A1, A2 and 35 percent for B1, B2 concrete exposure classification when determined in accordance with AS1141.22.

Therefore, the result of wet/dry strength variation can be acceptable in this experiment.

4.6 Los Angeles Abrasion AS1141.23

The method is for the determination of the loss, on abrasion, of aggregate particles by means of the Los Angeles abrasion testing machine.

4.6.1 Apparatus and Test Procedure of Los Angeles Abrasion

Apparatus:

- **Balance** of capacity not less than 16kg and with a limit of performance not exceeding ±0.5g.
- **Brusher** is suitable for cleaning sieves, containers and machine.
- **Los Angeles machine** refer to the Figure 4.11 as below.
- **Oven** with thermostatically controlled to operate at a temperature within the range 105°C to 110°C.
- **Sample dividers** (Figure 4.12)
- **Sieves** of 26.5mm, 19.0mm, 13.2mm, 9.5mm, 4.75mm, 1.70mm and pan complying with AS1152.

Figure 4.11 Los Angeles machine

Figure 4.12 Sample Dividers

Test Procedure:

1. Prepare the required unwashed amount of test fraction by sieving representation material on appropriate sieves by hand.
2. Place each separate fraction in a suitable wire mesh basket and wash material thoroughly by submerging and agitating the container and contents in running water until the water remains clear.
3. Oven-dry each fraction at 105°C to 110°C for a period of 15 to 16 hours.
4. Allow the material to cool by standing in laboratory ambient conditions for a minimum of 4 hours.
5. Obtain the required washed amounts of test fraction with the selection of test grading shall be according to the size of test fraction refer to Table 2 of AS1141.23.
6. Check and record the mass of the test portion to the nearest gram.
7. Select and make up appropriate steel ball charge and check the mass of total charge.
8. Inspect the Los Angeles abrasion testing machine for cleanliness and brush out the dust.
9. Place the test portion and steel ball charge in the machine, place the cover-plate into position and tighten the cover-plate clamp-nuts evenly and securely.
10. Set the revolution counter to 500 and allow the machine to operate continuously for 500 revolutions.
11. On completion, remove the cover-plate, turn the drum until the aperture is at the bottom and then remove the test portion and charge of the steel balls from the drum into the tray by hitting the drum with rubber mallet and then cleaning the interior thoroughly with soft brush. Try to avoid loss of materials.

12. Sieve the test portion by hand.

13. Wash all material coarser than 1.70mm in a 300mm diameter 1.70mm sieve under running water until the water remains clear.

14. Transfer the washed material to a suitable container and over-dry at 105°C to 110°C a minimum of 16 hours.

15. Cool the material for a minimum period of 1 hour to 23±2°C and sieve the test portion by hand.

16. Weigh all the material retained on the 1.70mm sieve and recorded to the nearest gram.

17. Calculate the percentage of mass before and after abrasion.

18. Report the Los Angeles value to the nearest whole number.

4.6.2 Result and Analysis

The Los Angeles abrasion value of the recycled aggregate is 43 percent of sized 20mm and 29 percent of sized 14mm fraction. These values are higher than those for virgin aggregates and arise because of the adhering cement paste. It is possible to allow for the abrasion loss in the mixture proportion because the aggregate itself does not break down. Besides, the maximum Los Angeles value is 40 percent for A1, A2 and 35 percent for B1, B2 concrete exposure classification, when determined in accordance with AS1141.23. Therefore, the result can be acceptable in this experiment.

4.7 Determination of Soundness of Sodium Sulphate AS1141.24

This method for testing of aggregates to determine their loss of mass due to disintegration when exposed to sodium sulphate solutions over repeated cycles of wetting and drying. To judging the soundness of aggregate exposed to actual weathering conditions.

4.7.1 Apparatus and Test Procedure of Sodium Sulphate Soundness

Apparatus:

- **Balance** of suitable capacity of not less than 5kg and with a limit of performance not exceeding ±0.5g.
- **Constant temperature room** shall operate in such a manner that the temperature of sodium sulphate solution is maintained at 23±1°C at any point in the area of the solution at a depth not less than 75mm below the surface of the solution.
- **Containers** with covered for immersing the samples of aggregate in the solution.
- **20/20 Hydrometers** complying with the requirements of AS2026 and capable of measuring solution density within the range of at least 1.155g/ml to 1.170g/ml with an accuracy of ±0.001g/ml.
- **Evaporation oven** capable of being continuously at 105°C to 110°C.
- **Sieves** complying with AS1152 in square woven wire in sizes 26.5mm, 19.0mm, 13.2mm, 9.5mm, and 4.75mm.

- **Thermometer**, a partial or total immersion thermometer or other suitable temperature measuring device with a temperature range of 0-50°C and graduated to 1°C or less with an uncertainty of no more than 0.5°C.

- **Reagents** – 215g of technical grade anhydrous sodium sulphate salt per litre of clear potable water to produce a saturated solution at 22°C. The mixture may be heated and stirred to aid in dissolving the salts. Prepare sufficient solution to exceed at least five times the solid volume of the aggregate to be tested. Allow the solution to stand at 23°C for at least 24 hours. Measure and record the density of the solution at 23°C using the 20/20 hydrometer.

Test Procedure:

1. Washed the test portion obtained over the smallest retained sieve of 4.75mm.

2. Dry the washed test portion to constant mass in a drying oven at 105°C to 110°C.

3. Weigh the minimum test fraction mass for coarse aggregate shown in Table 1 of AS1141.24.

4. Immerse the containers with the test fractions in the prepared solution of sodium sulphate so that the test fractions are covered by solution to a depth at least 15mm.

5. Maintain the temperature of the solution at 23°C±1°C for 16 to 18 hours. Do not agitate the test portion during the immersion period.

6. At the end of the immersion period, remove the test portions from the solution. Allow the test portions to drain for a period of 15±5 mins.

7. Dry the test portions to constant mass in the evaporation oven operating at 105°C to 110°C through the day.

8. Allow the test portions to cool and then re-immerse in the solution. Continue the process of immersion and drying for a total of five cycles.

9. At the completion of the fifth cycle, allow the test portions to cool. Place the test portions in warm water and dissolve the sodium sulphate from the test fractions. Wash the test fraction to avoid any loss of test material.

10. Ensure that test fractions are free of sodium sulphate by mixing a small amount of the wash water with a dilute solution of barium chloride. If no white precipitate appears then the fractions are free of sulphate.

11. Dry the test fractions to constant mass in the oven operating at 105°C to 110°C.

12. Hand sieves each test fraction over the separating sieve appropriate for the fraction size as given in Table 3 of AS1141.24.

13. Weigh and record the mass of the material retained on the sieve.

14. Calculate the individual fraction percent loss and report to nearest 0.1 percent.

4.7.2 Result and Analysis

The result shown that there is an approximate 14 percent loss of sized 20mm recycled aggregate and 4.0 percent loss of size 14mm recycled aggregate. According to the table 6 of AS2758.1- 1998, there is 2 percent loss higher than specification of concrete exposure condition A1 & A2. However, sized 20mm and 14mm recycled aggregate have been used in the mix design which is lower the percentage loss in the concrete.

4.8 Organic impurities other than sugar AS1141.34

This method for an approximate determination of the presence of organic materials other than sugar present in fine aggregate.

4.8.1 Apparatus and Test Procedure of Organic impurities other than sugar

Apparatus:

- **Stoppered rectangle clear glass bottles** of approximately 350ml or greater capacity.
- Stoppered glass measuring cylinders as required.
- **Sodium hydroxide solution** of 30g sodium hydroxide (AR Grade) in 970ml of distilled water.
- **Reference colour solution** of two grams of tannic acid (AR Grade) shall be dissolved in 10ml of ethanol (ethyl alcohol AR Grade), and the solution diluted to 100ml with distilled water, then 2.5ml of resultant solution shall be added to 97.5ml of 3 percent sodium hydroxide. The mixture shall be shaken vigorously and then allowed to stand in subdued light for 1 hour before use. The reference colour solution shall be used within 2 hours of its preparation.

Test Procedure:

1. Pour about 50ml of 3 percent sodium hydroxide solution into a rectangle clear glass bottle. Add the fine aggregate to the 125ml mark and adjust the sodium hydroxide level to the 200ml mark with more solution.

2. Vigorously shake the mixture for not less than 30 second, ensure all the fine aggregate is thoroughly wetted by the sodium hydroxide solution and any lumps are dispersed. After shaking, allow the mixture to stand for approximately 24 hours.

3. At the end of 24 hours standing period, place 100ml reference colour solution in the rectangle clear glass bottle. Compare the colour of the reference solution with the colour of the supernatant liquid from the test by holding the two bottles side by side and looking through them.

4. If the results of visual or instrumental colour assessment indicate that the solution is lighter than the reference and the result of test is a Pass. Otherwise is Fail.

4.8.2 Result and Analysis

The result of the fine fraction in this test is a PASS. It showed the amount of organic impurities present in the recycled aggregate is not significant.

4.9 Conclusions

From the laboratory experimental results shown above, there is some amount of old mortar attached to the coarse aggregate which may have detrimental effects on the properties of fresh and hardened concrete, but this will still depend on the strength of the original concrete.

Chapter 5

Experimental Methodology

5.1 Mix Design of RCA

The design of a concrete mix, refer to Table 5.1, is usually based on a compressive strength which is sufficient to achieve both of two principal requirements of the hardened concrete for obtaining good quality concrete.

- The water/cement ratio should be low enough to give the required strength for structural and durability purposes.
- The mix should be workable and cohesive enough to ensure a thoroughly compacted and homogenous material.

Therefore, it is very important to find out particle size distribution or grading of aggregate, shape of aggregate, particle oven dry density and water absorption, moisture content of aggregate to design the mix. The target strength of the first trial mix for both 100 percent recycled and virgin concrete with fly ash is 40MPa. The water/cement ratio is 0.42, the aggregates constitute over 60 percent of the total volume of the concrete including 60 percent of coarse aggregate and 40 percent fine aggregate for both recycled and natural concrete trial mix in this experiment.

Batch per 10 Litres	Cement	Fly ash	Water	20mm RA	14mm RA	20mmSA	10mmSA	Coarse Sand	Fine Sand
Price per Ton	$180	$75		$20	$20	$30	$33	$30	$30
SA1 (kg)	3.6	1.2	1.767			5.83	4.51	6.04	0.86
RA1 (kg)	3.6	1.2	1.921	5.26	4.14			5.31	0.76
RA2 (kg)	3.6	1.2	1.866		9.44			5.31	0.76

Table 5.1 Proportional of mix design

5.2 Mixing and moulding of Concrete (Mixes) AS1012.02

The objective of mixing is to obtain a uniform and consistent of cement, water, aggregate, sand and any admixtures used in the concrete and also to meet the requirement of the standard.

There are and six cylinders and three prisms in each batch and approximately four trial batches and all the mix are prepared in accordance with clause 10 and mix design (refer to Appendix).

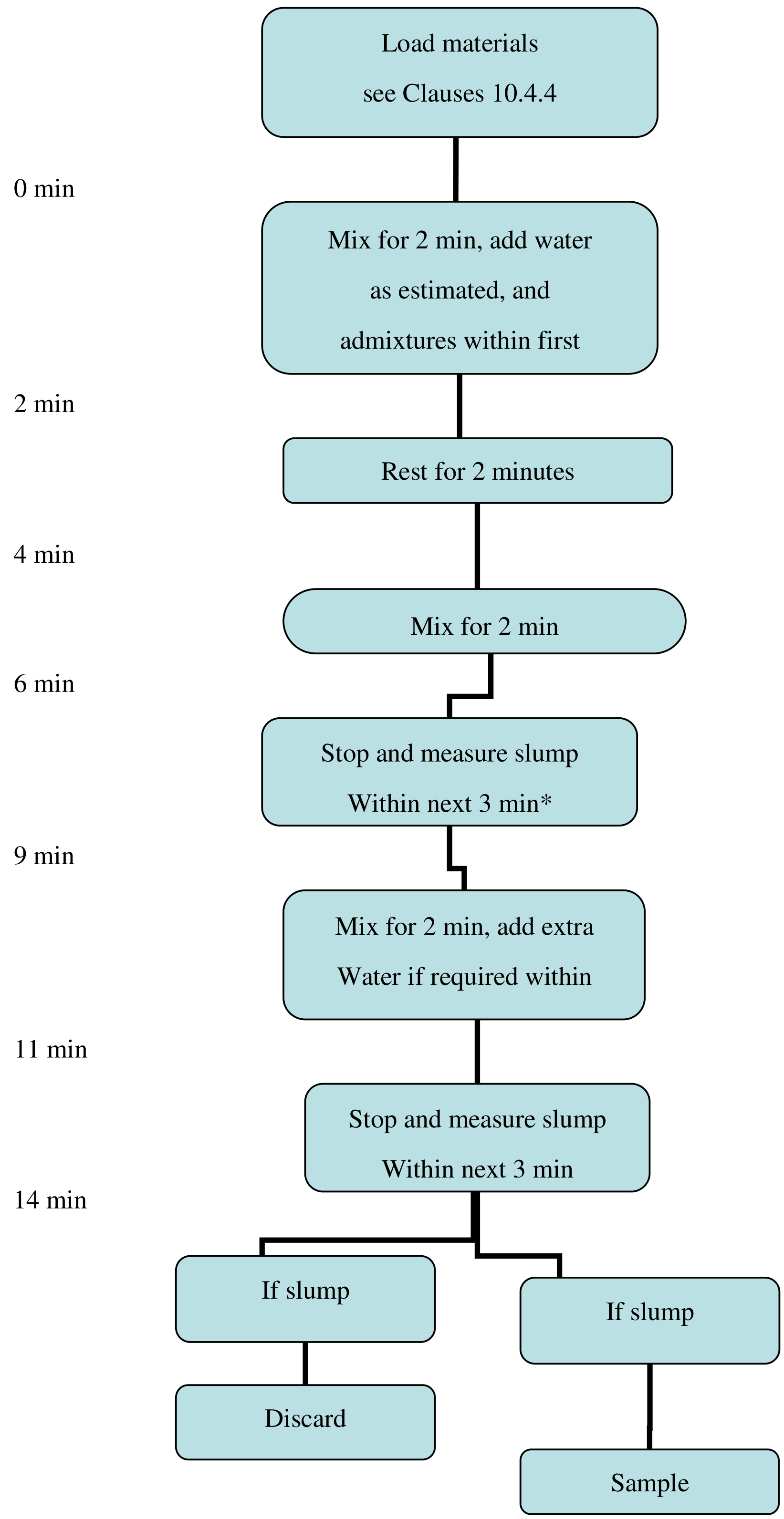
Apparatus:

- Pan Mixer (Figure 5.2) consists of a cylindrical pan rotating about a vertical axis with capacity of 20 - 25 litres mixing. One set of paddles rotate within the pan also on a vertical axis.

Figure 5.2 Pan Mixer at Herston Laboratory

Test Procedure:

1. Weigh all materials according to the mix design.
2. Clean up the inside of the pan mixer by wet wipe.
3. Use a small amount of cement, coarse and fine sand to wipe the inside surface of the pan mixer to prevent any lost materials of the batch.
4. Place the coarse aggregate into the mixer first, then the coarse and fine sand, cement and fly ash.
5. Start and adding the water within the first minutes refer to Figure 5.3.
6. Stop after first two minutes and remove any materials have been adherent at the inside surface or paddle back to mixer during the rest two minutes.
7. Then mix for two minutes.
8. Stop and measure the slump within the range of 60mm and 100mm during next three minutes.
9. Check the ambient and concrete temperature with a partial or total immersion thermometer.



* The concrete used in the slump needs to be returned to the mixer

Figure 5.3 Mixing Procedure

(Source: Australian Standard)

5.2.1 Workability Tests of Fresh Concrete and Slump Test AS1012.03

This test is to determine the slump of concrete, when the nominal size of aggregate does not exceed 40mm. The method also describes the procedure of filling a slump cone with fresh concrete in layers, rodding each layer 25 times and then removing the support given to the concrete by the slump cone by raising the slump cone vertically upwards away from the concrete. The vertical subsidence of the concrete that occurs, when the slump cone is raised, is the termed the 'slump' of the concrete.

5.2.1.1 Apparatus and Test Procedure of Slump Test

Apparatus:

- **Mould** (Figure 5.4) shall be a hollow frustum of a cone manufactured from galvanized steel sheet with thickness of between 1.5mm to 2.0mm, the bottom and the top of the mould being open and at right-angles to the axis of the cone. The mould shall be provided with suitable foot-pieces and handles or other means of holding in place during filling and its internal surface shall be smooth.

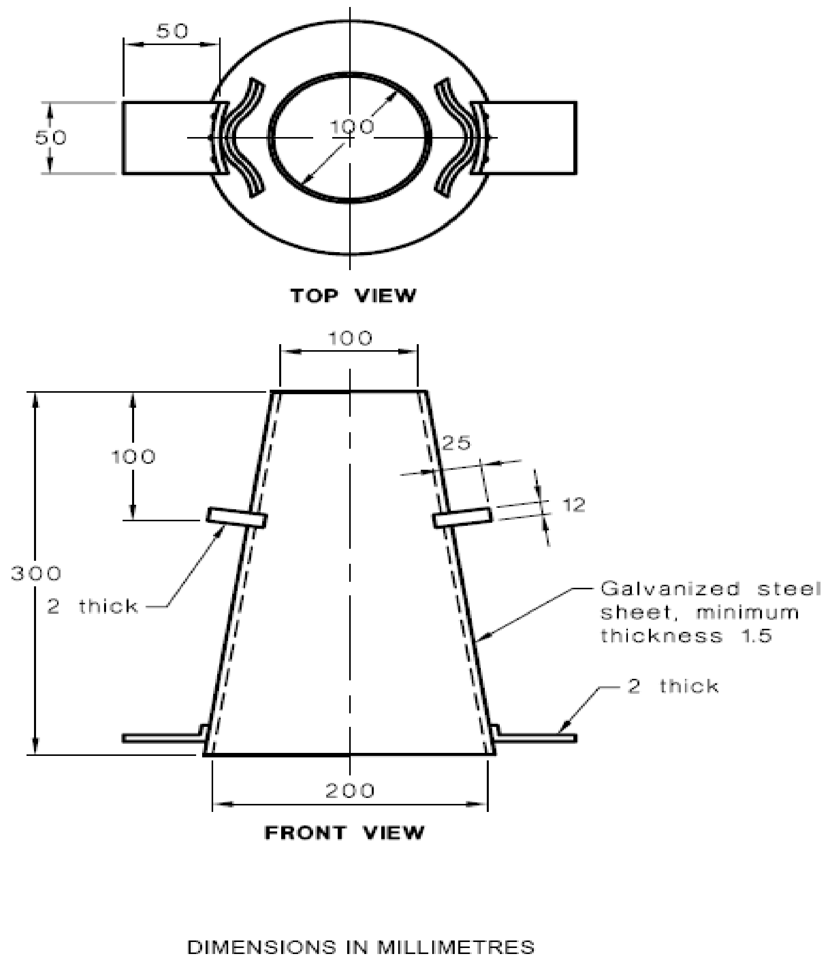


Figure 5.4 Typical mould for slump test

(Source: Australian Standard)

- **Rod** (Figure 5.5) used to for compacting concrete in the mould shall be a metal rod of 16±1mm in diameter, approximate 600mm long and having at least one end tapered for a distance of approximately 25mm to a spherical shape having a radius of approximately 5mm.
- **Scoop** (Figure 5.5) shall be made from non-absorbent material not readily attacked by cement paste and suitable for taking increments of concrete.
- **Baseplate** (Figure 5.5) shall be of shall be of smooth, rigid, non-absorbent material.
- **A steel ruler** (Figure 5.5)

Figure 5.5 Moulds, Rod, Scoop and Baseplate

Test Procedure:

1. For concrete made in the laboratory, the test sample shall be prepared in accordance with AS1012.2.
2. Ensure that the internal surface of the mould is clean and free from set concrete.
3. Moisten the internal surface of the mould by wiping with a damp cloth immediately before commencing each test.
4. Place the mould on a smooth horizontal levelled base place. Hold the mould firmly in place by standing on the foot-pieces against the base plate while the mould is being filled.
5. Fill the mould in three layers each approximately one-third of the height of the mould.
6. Rod each layer with 25 strokes of the rounded end of the rod.
7. After the top layer has been rodded, strike off the surface of the concrete by using a screeding and rolling motion of the rod so that the mould is filled exactly.
8. Immediately remove the mould from the concrete by raising it slowly and carefully in a vertical direction, allowing the concrete to subside.
9. Immediately measure the slump by determining the difference between the height of the mould (300mm) and the average height of the top surface of the concrete to the nearest 5mm for slumps of 100mm and less.
10. Tapping the surface of the baseplate to check the workability.
11. Records identification of the concrete, laboratory where tested, date and time of test, slump, identification of testing operator.
12. Report the slump to the nearest 5mm.

5.2.2 Method for making and curing concrete AS1012.8.1

This method is for making and curing of compression and indirect tensile test specimens of concrete sample in the laboratory.

5.2.2.1 Apparatus and Test Procedure

Apparatus:

- **Cylinder mould** (Figure 5.7) is clamped and the dimeter and height shall be 100mm x 200mm.
- **Internal Vibrators** used for the compaction of concrete shall have a frequency of vibration of at least 115Hz.
- **Steel Rammer** used for compaction of low slump concrete shall comply with relevant requirements of AS1012.3.4.
- **Mallet** used in the moulding of the specimens shall comply with relevant requirements of AS1012.4.1, AS1012.4.2 and As1012.4.3.
- **Scoop** used for sampling concrete with capacity of not less than 1L.
- **Lime-saturated water tank** (Figure 5.6) with the constant temperature of 27±2°C.

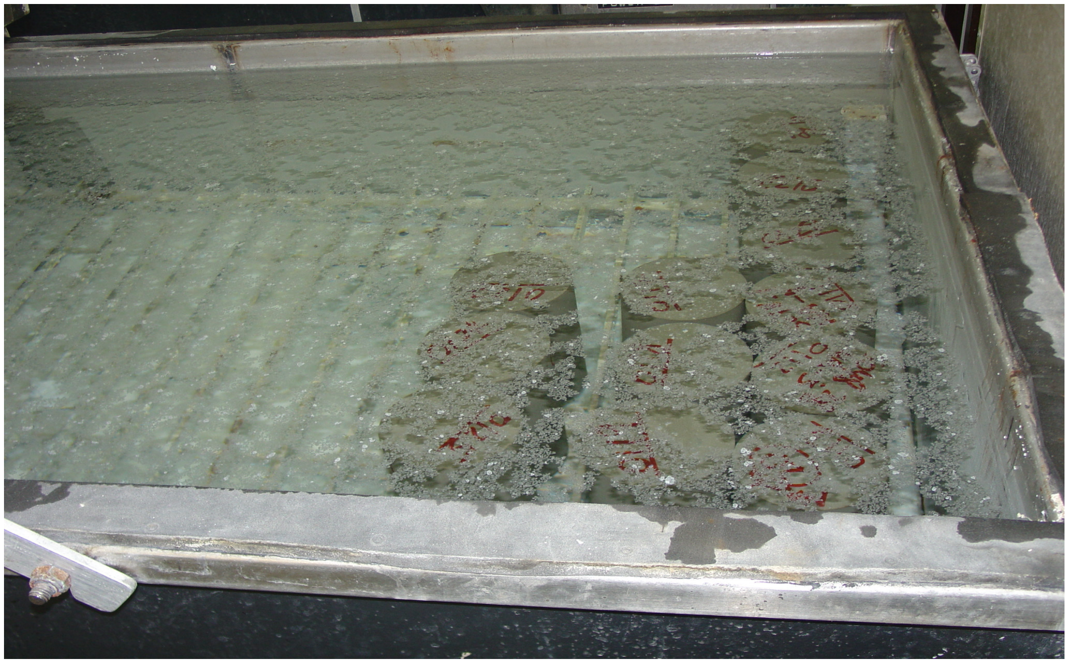


Figure 5.6 Lime-saturated water tanks

Figure 5.7 Cylinder Mould

Figure 5.8 Drying Shrinkage Mould

Test Procedure:

1. Clean the cylinder mould.
2. Coat the inside lightly with form oil including the baseplate and cover to prevent adhesion of the concrete when release.
3. Place the cylinder on a clean, level and firm surface.
4. Fill two approximately equal layers concrete in the mould by using a scoop.
5. Compact the concrete without causing segregation and drive the excessive air bubbles out by vibrating.
6. Vibrate each layer until the surface becomes relatively smooth in appearance.
7. Level off the top with the steel float and clean any concrete from around the mould.
8. Put the cylinder in cool dry place for at least 18 hours.

9. Remove the cylinders from the mould between 18 hours to 36 hours after moulding.

10. Place the cylinders in lime-saturated water tank in standard moist-curing conditions to ensure that the concrete specimens are kept at a temperature of 27±2°C for the Standard Tropical Zone including Queensland.

5.3 Part I Testing on Hardened Properties of Concrete Cylinders Specimens

5.3.1 Compressive Strength of Concrete AS1012.1

This test is to determining the compressive strength of the concrete test specimens.

5.3.1.1 Apparatus and Test Procedure of Compressive Strength of Concrete

Apparatus:

- **Test machine** refer to Figure 5.9 shall meet the requirements for Grade A machine defined in AS2193 for the relevant range of compressive force.

Figure 5.9 Compressive Test Machine

Figure 5.10 Sulphate Mixture

Figure 5.11 Capping Plate

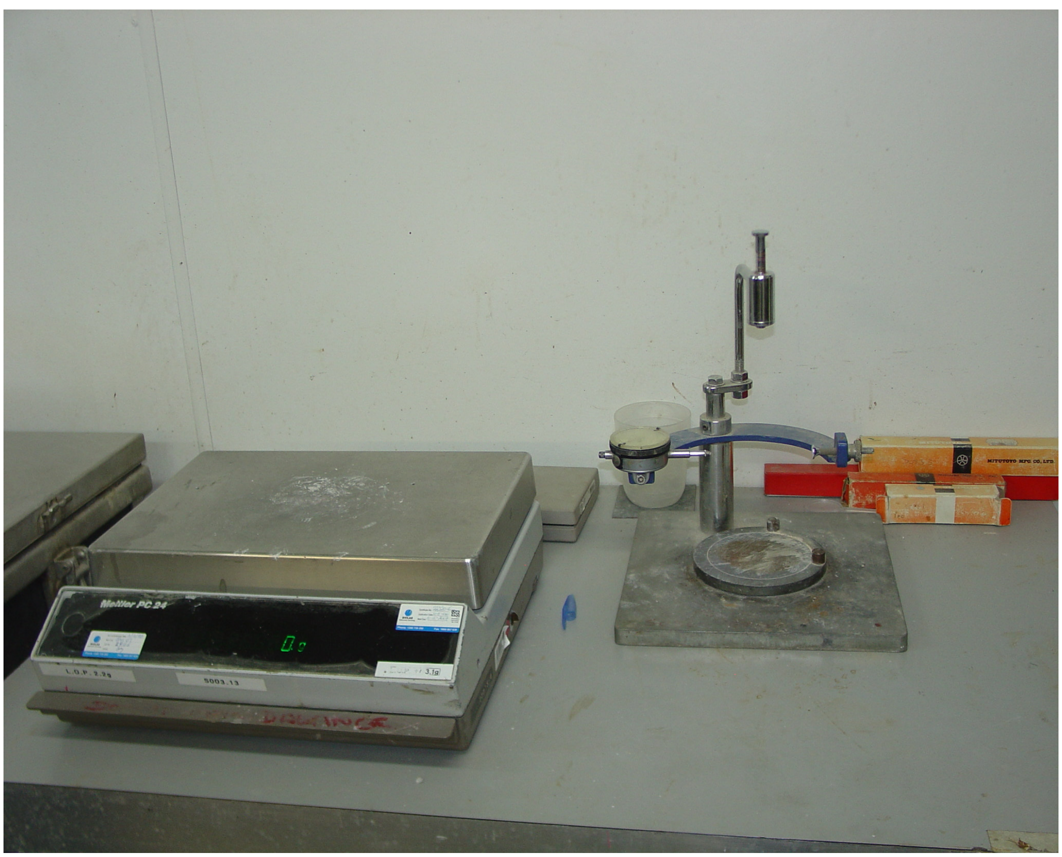


Figure 5.12 Measuring equipment

Test Procedure:

1. Remove the test cylinder from the lime-saturate tank on the due date of the test period.
2. Record and measure the diameter, height and weigh the mass of the cylinder by using the measuring equipment as Figure 5.12.
3. Capping plate (Figure 5.11) shall be thinly coated with mineral oil to prevent adhesion of the capping material to the plate.
4. Place the Sulphate mixture (Figure 5.10) into the capping plate.
5. Place the rough end of the cylinder on the capping plate immediately and hold down vertically firm.
6. Remove the cylinder from the capping plate and cover them with wet towel at 23°C for a period of 2 hours before testing.
7. Clean up the plates of the testing machine with a clean rag.
8. Wipe or brush the free loose particles of girt from uncapped bearing surface of cylinder.
9. Place the cylinder in the machine and align the axis of the specimen with the centre of thrust of the spherically seated platen.
10. Bring the upper plate and the capped cylinder together but leave approximately 1mm gap in between them so that the uniform bearing is obtained.
11. Apply the force without shock and increase continuously at a rate equivalent to 20±2 MPa compressive stress per minute until no increase in force can be sustained.

12. Record the maximum force applied to the cylinder as indicated by the testing machine.

13. Calculate the compressive strength of the cylinder by dividing the maximum force applied to the cylinder by the cross-sectional area.

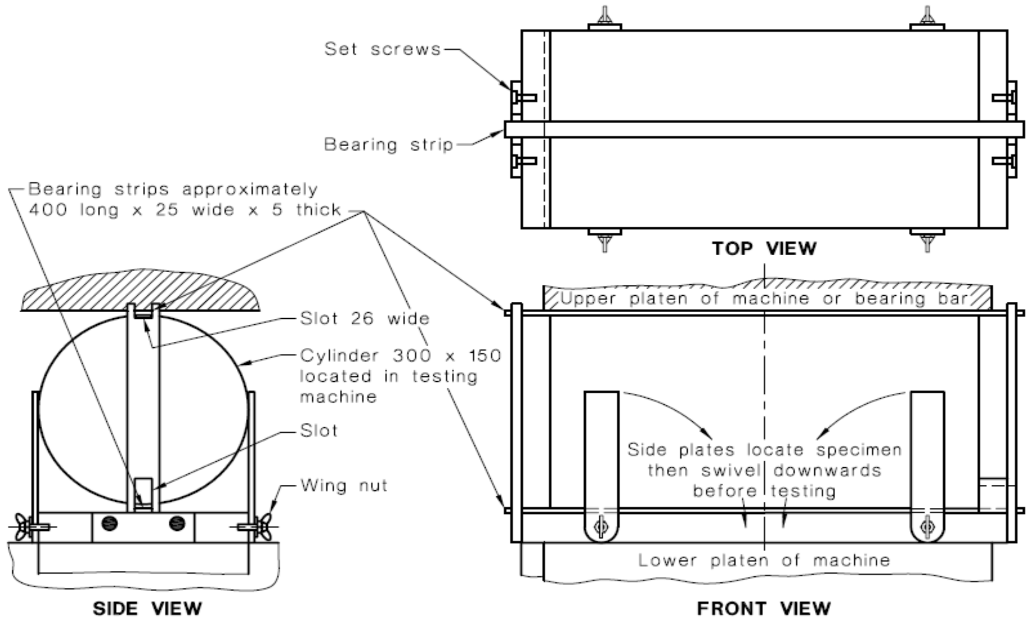
5.3.2 Indirect Tensile Test AS1012.10

The test is to determining the indirect tensile strength of the standard concrete cylinders, prepared in accordance with AS1012.8.1.

5.3.2.1 Apparatus and Test Procedure of Indirect Tensile Test

Apparatus:

- **Testing Machines** shall meeting the requirements of Grade A machines as defined in AS2193 for the relevant range of compressive forces.
- Appropriate steel **testing jip** refer Figure 5.13 and 5.14 shall be used to ensure that the specimen cab be located centrally on the lower platen of the testing machine, with the bearing strips aligned in a vertical plane passing through the axis of the specimen.
- Two **bearing strips** of tempered grade hardboard, complying with AS2458, shall be free from defects, normally 5mm thick, 25mm wide and shall not be used again.
- **Vernier calliper** readable to at least 0.2mm and complying with the requirements of AS1984.
- **Ruler** at least 400mm long with a scale interest of 0.5mm.



DIMENSIONS IN MILLIMETRES

Figure 5.13 Typical Jig for locating 150mm diameter concrete test

Cylinders for indirect tensile strength test

(Source: Australian Standard)

Figure 5.14 Typical Jig

Figure 5.15 Jib Marker

Test Procedure:

1. Determine the diameter of the test cylinder in the test plane to the nearest 0.2mm by averaging three diameters measured near the ends and the middle of the specimen.
2. Determine the length of the test cylinder to the nearest millimetre by averaging at least two length measurements by using Jib Marker as Figure 5.16. Make length measurements along the lines in contact with the bearing strips.
3. Align the hardboard bearing strips between the top and bottom platen of the specimen.
4. Apply a small initial force and remove any side constraint by lowering the side plates in the case of the testing jig.
5. Apply the force without shock and increase continuously at a constant rate of 1.5±0.15MPa/min indirect tensile stress until no increase in force can be sustained.

6. Record the maximum force applied to the specimen as indicated by the testing machine.

7. Calculate the tensile strength of the cylinder as below.

$$T = \frac{2000P}{\pi LD}$$

where

T = indirect tensile strength, in megapascals

P = maximum applied force indicated by the testing machine, in kilonewtons

L = length, in millimetres

D = diameter, in millimetres

· Report the indirect tensile strength to nearest 0.1MPa.

5.3.3 Determination of the modulus of rupture AS1012.11-2000

This test is for determining the modulus of rupture of concrete test specimens prepared in accordance with AS1012.8.2 tested as simple unreinforced beams with third-point loading.

5.3.3.1 Apparatus and Test Procedure of modulus of rupture

Apparatus:

- Testing machine shall meet the requirements for Grade A machine.
- Flexure testing apparatus refer to Figure 5.17. The force shall be applied to the beam through a frame containing two supporting rollers and two loading rollers.

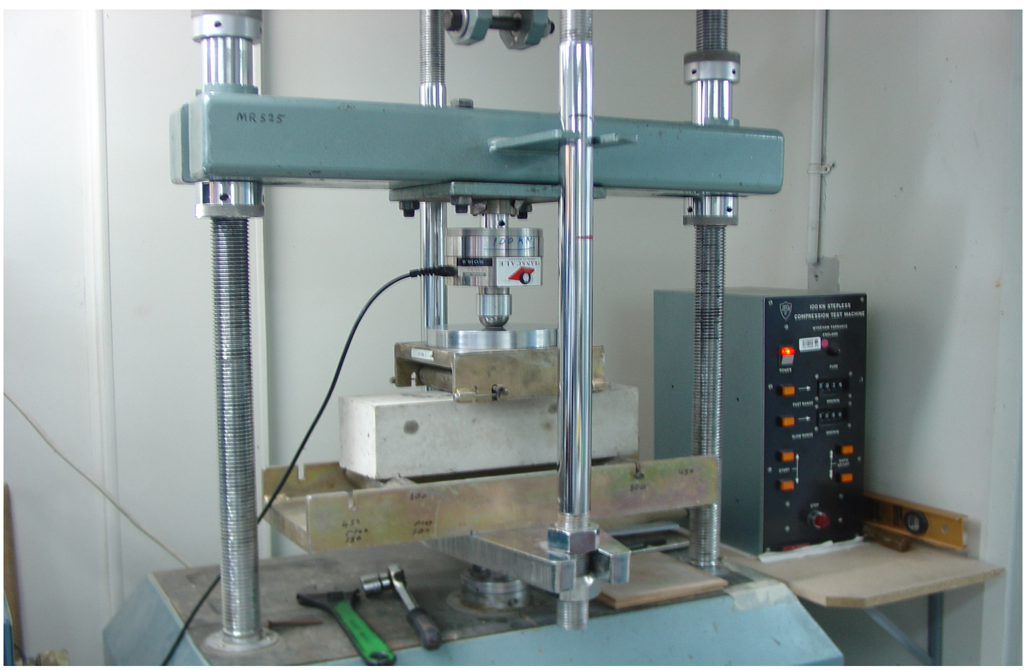


Figure 5.16 Flexure testing apparatus

- Ruler readable to at least 1mm.

Test Procedure:

1. Remove grit from the surface of the flexure beam that is loaded and wipe to remove the surplus water if needed.
2. Centre the beam on the supporting rollers with the length of 450mm.
3. Bring the loading rollers into contact with the top surface; apply a seating load not exceeding 100N.
4. Apply the force without shock and increase continuously at a rate equivalent to 1±0.1 MPa/min extreme fibre stress until no increase in force can be sustained.
5. Record the maximum force applied to the specimen as indicated by the testing machine.
6. Determine the average width and average depth of the specimen at the section of failure to the nearest 1 mm.
7. Calculate the modulus of rupture as follows:

$$f_{cf} = \frac{PL\ (1000)}{BD^2}$$

where

f_{cf} = modulus of rupture, in megapascals

P = maximum applied force indicated by the testing machine, in kilonewtons

L = span length, in millimetres

B = average width of the specimen at the section of failure, in millimetres

D = average depth of specimen at the section of failure, in millimetres

5.4 Part II Testing for Durability and Permeability of Concrete

5.4.1 Drying Shrinkage of Concrete of Prism AS1012.13

The method is to preparing and curing of concrete shrinkage of prisms and for determining the length changes of prisms due to drying in air by controlled temperature.

5.4.1.1 Apparatus and Test Procedure of Drying Shrinkage of Concrete Test

Apparatus:

- Drying room (Figure 5.18) with controlled temperature which shall be maintained at 23±1°C for 90% of each 24 hours period and at all times remaining within the range 23±2°C, the relative humidity shall be maintained at 50±5% at all time and air circulation.

Figure 5.17 Drying room

- Moulds shall be made of non-absorbent material which does not react with cement paste with internal size of 280mm x 75mm x 75mm.
- Gauge studs.
- Length gauge shall have a diameter of at least 6mm.
- Tamping bar used for compacting concrete in the moulds by hand shall be a straight metal rectangular bar having nominal dimensions of 25mm x 10mm x 300mm.
- Comparator as Figure 5.19

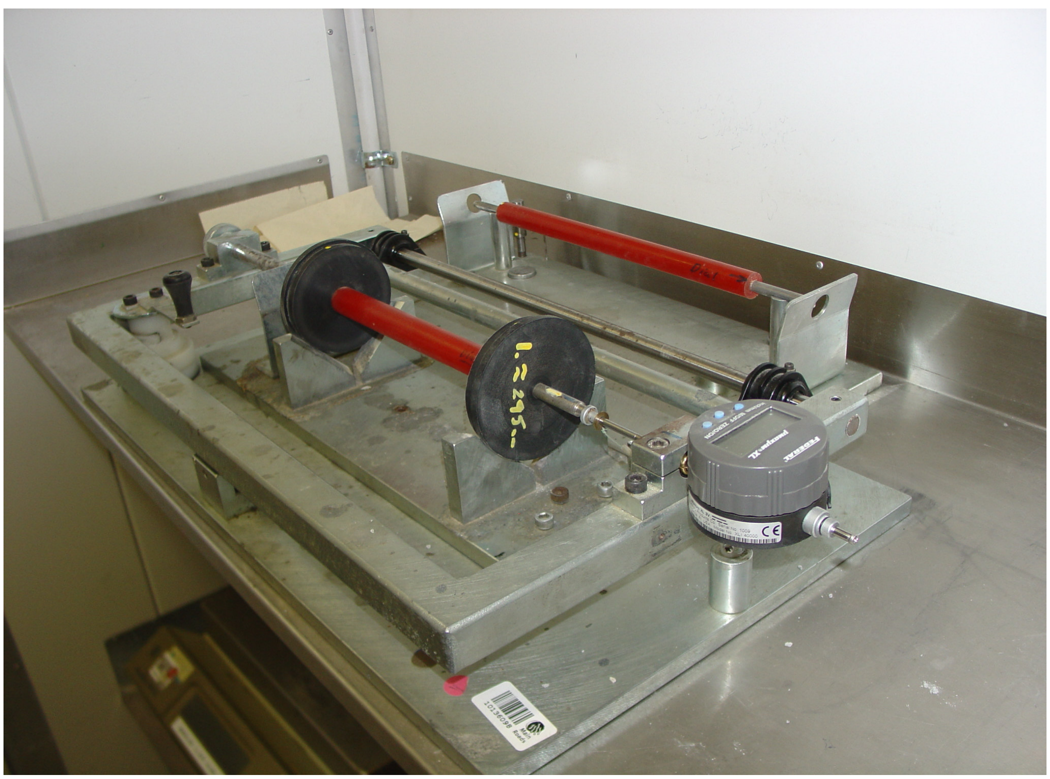


Figure 5.18 Comparator

Test Procedure:

1. Mixing the concrete as mention as before.
2. Place the concrete in the mould in two approximately equal layers by using a scoop for three set of prisms.

3. Compact the concrete by tamping with at least 35 times per layer.

4. Strike off and smooth the surface of the concrete with a wooden float.

5. Place the mould containing the specimen in the initial curing environment and loosen the gauge stud holder retaining screws to prevent shrinkage of the concrete during the initial curing within 27±2°C.

6. De-mould the specimens within 24±2 hours from the time of moulding.

7. Place the prisms into Lime-saturated water tanks for 6 days from the time of moulding.

8. Moved the prisms into Lime-saturated water basket and stored into the drying room for one day to make sure under same temperature when taking initial reading.

9. Remove the prisms one by one at a time and wipe the surface dry with a damp cloth at the end 0f 7-day periods.

10. Check the zero setting of the reference bar.

11. Taking the replicate measurements until at least five consecutive determinations have been made within 0.001mm during first 2 minutes after removed from Lime-saturated water.

12. Check the zero setting of the comparator.

13. Record the length of the prisms, reference bar, date, temperature before and after measurement.

14. Repeat taking the measurement for curing period of 7-day, 14-day, 21-day, 28-day and 56-day.

5.4.2 Determination of the Static chord Modulus of elasticity of concrete specimens AS1012.17-1997

This test is to determining the static chord modulus of elasticity (Young's modulus) of mould concrete cylinders and cores based on the test load of 40 percent of the average compressive strength of the concrete.

5.4.2.1 Apparatus and Test Procedure of Modulus of elasticity of concrete specimens

Apparatus:

- **Compression Testing Machine**
- **Deformation-measuring apparatus** shall consist of a sensing device suitable for measuring the deformation to the nearest 10x10¯6 m/m.
- **Compressometer** as Figure 5.20 consists of two yokes, one of which is rigidly attached to the specimen and the other attached at two diametrically opposite points. At one point on the circumference of the rotating yoke, midway between the two supporting pivot points, a pivot rod shall be used to maintain a constant distance between the two yokes. At the opposite point on the circumference of the rotating yoke, the change in distance between the yokes (i.e., the gage reading) is equal to the sum of the displacement due to specimen deformation and the displacement due to rotation of the yoke about the pivot rod.
- **Demountable gauge**
- **Attached Strain gauges**

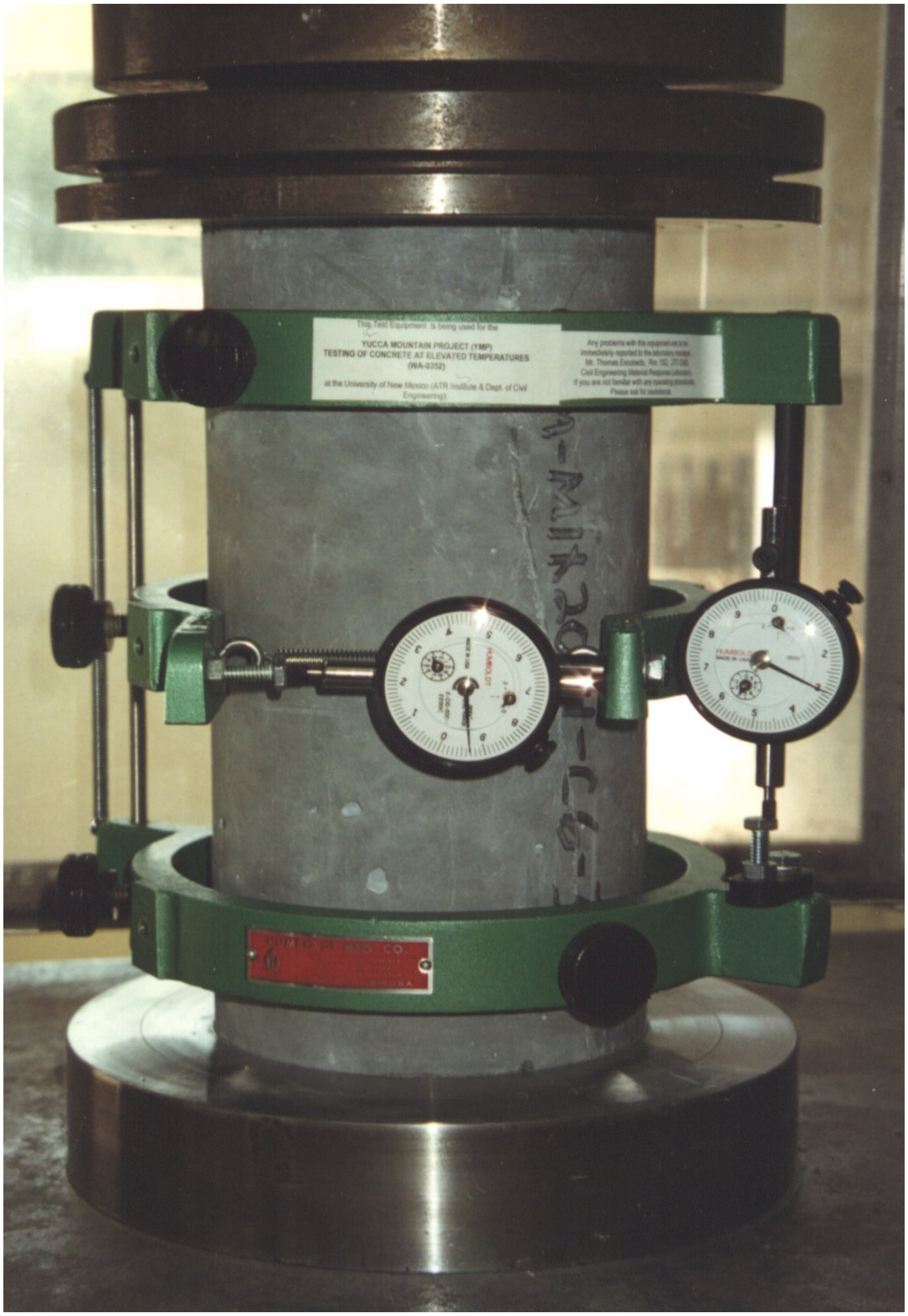


Figure 5.19Compressometer

Test Procedure:

1. Attach the compressometer to the test specimen.
2. Place the specimen, with attached compressometer, on the lower platen of the test machine.
3. Carefully align the axis of the specimen with the centreline of the upper thrust block of the crosshead.
4. Lower the crosshead down until contact is almost made with the specimen.
5. Zero the dial gages.
6. Load the specimen at a rate within the range 15±2 MPa/min.
7. If the dial gage readings (deformations) are not zero, repeat pervious step until the dial gages, upon unloading, are zero.
8. Perform the final loading cycle and continue the loading until 40% of ultimate load is achieved, recording without interruption, the applied load and longitudinal deformation at set intervals. (Load slowly, recording dial gage readings at 2000 lb increments; if data acquisition is used, sample deformations and load simultaneously once per second).
9. Calculate stress and longitudinal strain as follows:

Stress, $\sigma = P/A$

where P is the applied load and A is the cross-sectional area of the cylindrical specimen.

Strain, $\varepsilon_x = d/L_o$

where d is the longitudinal specimen deformation and L_o is the gage length.

The deformation, d is equal to $d = gI$

where g is the longitudinal dial gage reading and

$$I = \frac{e_1}{e_1 + e_2}$$

where e_1 is the eccentricity of the compressometer pivot rod from the axis of the specimen and e_2 is the eccentricity of the longitudinal dial gage from the axis of the specimen. If these eccentricities are equal, then $I=0.5$. The gage length is the distance between yokes, and is generally equal to 8 in. (for 6 in. diameter specimens).

10. Plot the stress-strain curve (stress on the ordinate and strain on the abscissa).
11. Calculate E as follows:

$$E = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - 0.00005}$$

where σ_2 is the stress corresponding to 40% of ultimate load, σ_1 the stress corresponding to a strain of 0.00005, and ε_2 the strain at a stress of σ_2.

12. Calculate lateral (radial) strain as follows:

Strain, $\varepsilon_y = d'/D$

where d' is the radial specimen deformation and D is the specimen diameter.

The deformation, d' is equal to $d' = g'I'$

where g' is the radial dial gage reading and

$$I' = \frac{e'_1}{e'_1 + e'_2}$$

where e'_1 is the eccentricity of the extensometer pivot rod from the axis of the specimen and e'_2 is the eccentricity of the radial dial gage from the axis of the specimen. If these eccentricities are equal, then $I'=0.5$.

13. Plot the lateral strain versus the longitudinal strain curve (lateral strain on the ordinate and longitudinal strain on the abscissa).

14. Calculate ν to the nearest 0.01 as follows:

$$\nu = \frac{\varepsilon_{t2} - \varepsilon_{t1}}{\varepsilon_2 - 0.00005}$$

where ε_{t2} is the lateral strain produced by stress σ_2, and ε_{t1} is the lateral strain produced by stress σ_1.

15. After loading to 40% and recording the load versus displacement data, unload the specimen.
16. Remove the compressometer (the compressometer may be left in place when appropriate to generate the entire stress vs. strain curve to failure).

5.4.3 Determination of water absorption and apparent volume of permeable voids in hardened concrete AS 1012.21

Concrete durability depends largely on the ease (or difficulty) with which fluids (**water, carbon dioxide, oxygen**) in the form of liquid or gas can migrate through the hardened concrete mass. Therefore, this test is for determining the immersed absorption (Ai) and boiled absorption (Ab) and apparent volume of permeable voids (AVPV) in hardened concrete.

5.4.3.1 Apparatus and Test Procedure of water absorption and apparent volume of permeable voids in hardened concrete

Apparatus:

- **Balance** of capacity with a limit of performance not exceeding ±0.5g.
- **Rack** with wire hangers for suspending the specimen in water.
- **Water tank** could provide cover of at least 50mm above the top of the immersed specimen when being weighed.
- **Thermometer** had graduated to 1°C with an uncertainty not exceeding 0.5°C.
- **Drying oven** with controlled temperature of 100°C to 110°C.
- **Water bath** with sufficient size for boiling the specimens.
- **Heater** could be boiling the water with specimens in the water bath.
- **Drying Towels**.
- **Dishes** with minimum size of 300 x 200mm.
- **Desiccator** with adequate size to accommodate the specimens.
- **Silica gel desiccant**.
- **Concrete saw** that equipped with a wet diamond masonry cutting blade.

Test Procedure:

1. Cut the 100 x 200mm test cylinder into four equal slices and trimmed to a maximum of 3mm of the top surface including the thickness of the saw blade.
2. For immersed absorption, weight the specimen to the nearest 0.1g.
3. Dry the specimens in a dish to oven for at least 24 hours.
4. After remove from oven, allow it cool in a desiccator to a temperature of 23±2°C for at least 48 hours.
5. Surface-dry the saturated specimen by removing the surface moisture with a towel.
6. Record the mass to the nearest 0.1g.
7. For boiled absorption and apparent volume of permeable voids, place the surface-dry the saturated specimen in water bath at room temperature and covered with water.
8. Boiled the specimen for a period of 5.5±0.5 hours.
9. Allow the specimen to cool to the final temperature of 23±2°C for at least 14 hours.
10. Weigh the mass of surface-dry boiled specimen.
11. Weigh the mass of specimen in water at 23±2°C suspend by rack after immersion and boiling to the nearest 0.1g.

12. Calculate the result as follows:

Immersion Absorption

$$= \frac{(M_{2i} - M_1)}{M_1} \times 100\%$$

Boiled Absorption

$$= \frac{(M_{3b} - M_1)}{M_1} \times 100\%$$

Apparent Volume of Permeable Voids

$$= \frac{(M_{3b} - M_1)}{M_{3b} - M_{4ib}} \times 100\%$$

5.4.4 Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration ATM 1202 – 97

This test method allows evaluation of chloride permeability characteristics of concrete.

The test is performed to monitor the amount of electrical current passing through 51mm thick slices of 102mm normal diameter concrete cylinders during a 6-h period and would take three to four days to complete.

A potential difference of 60V dc is maintained across the ends of the specimen, one of which is immersed in a sodium chloride solution, the other in a sodium hydroxide solution. The total charge passed, in coulombs, has been found to be related to the resistance of the specimen to chloride ion penetration.

5.4.4.1 Apparatus and Test Procedure of Chloride Ion Penetration

Apparatus:

- The meter consists of a digital unit for the generation, application and readout of the voltage, of a pair of symmetrical cells fitted with conductive retina, sensor and cables.
- Vacuum Saturation Apparatus
- Applied Voltage Cell as Figure 5.21

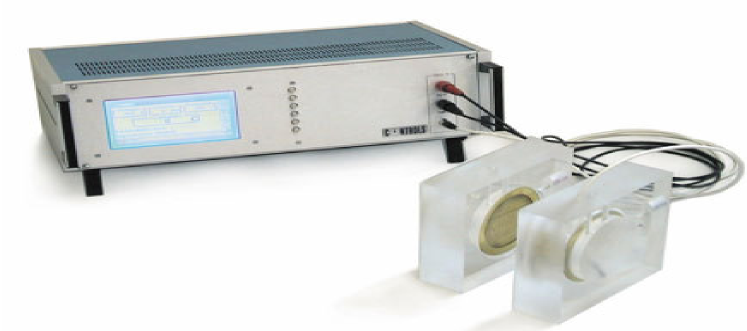


Figure 5.20 Applied Voltage Cell

Test Procedure:

1. Remove the cylinder from water and cut it to the size of test specimen.

2. Apply sealant around specimen-cell boundary and leave it set for overnight.

3. Place circular vulcanised rubber gasket in each of test cell.

4. Insert the specimen and clamp the two halves of the test cell together to seal.

5. Fill the side of the cell containing the top surface of the specimen with 3.0% NaCl solution and will be connected to the negative terminal of the power supply.

6. Fill the other side of the cell, which will be connected to the positive terminal of the power supply, with 0.3N NaOH solution.

7. Attach lead wires to cell banana posts. Make electrical connections to voltage application and data readout apparatus.

8. Read and record current at least every 30minutes.

9. Terminate test after 6 hours.

Chapter 6

Test Results and Discussion

6.1 Introduction

The compressive, tensile, shear and bond strengths of concrete are relatively important mechanical properties of any hardened concrete including recycled aggregate concrete. The recycled concrete must adopt the same conventional concreting practices in accordance with AS3600 to ensure the hardened concrete properties. The following results indicated that the required strength, durability and serviceability had been achieved to meet the requirements of high strength concrete criteria.

6.2 Slump Test Result and Analysis

All mixes contained natural coarse and fine sand and the water/cement ratio was 0.42. The measured concrete slump was 75mm for recycled concrete and 80mm for virginal concrete refer to Figure 6.1 which was within the limitation of 80±20mm slump for final compaction. It showed RCA concretes have a similar workability as conventional concrete, and there should be no difficulty in placing, finishing and casting.

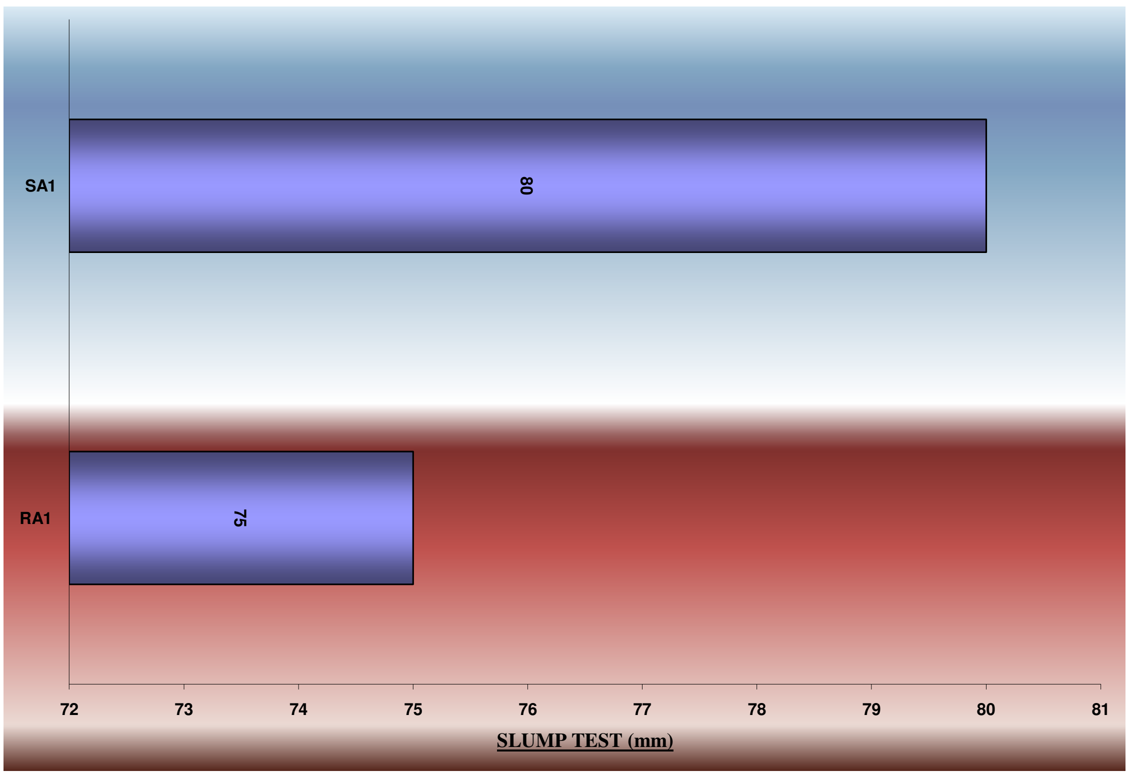


Figure 6.1 Result of Slump Test

6.3 Compressive strength Test Result and Analysis

According to Figure 6.3, the crack of the cylinder is shown broken in a similar way in both concretes. The 28-day standard lime-saturated cured cylinder compressive strength of 100% recycled concrete was between 49.5MPa and 48.0MPa. The equivalent strength of virginal concrete was between 54.5MPa and 57.5MPa. The results showed (refer to Figure 6.2) that the RCA mix was well over the target strength of 50.0MPa in 28-day age. In both cases, the compressive strength of recycled and control concretes were good and achieved to the target strength. Therefore, the Recycled Concrete Aggregate can be used to produce 50 MPa structural concrete.

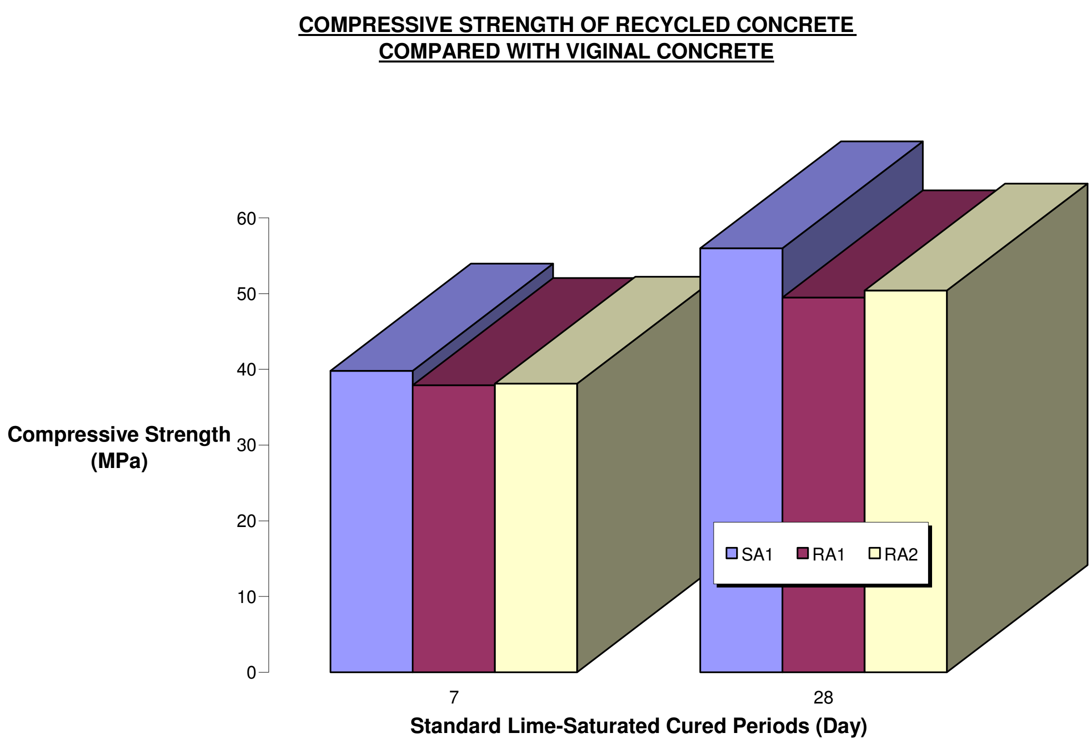


Figure 6.2 Compressive Strength Result

Figure 6.3 7-days Cylinder broken by compressive strength

6.4 Indirect Tensile Test Result and Analysis

The 28-day standard lime-saturated cured cylinder indirect tensile strength of 100% recycled concrete was between 4.94MPa and 4.33MPa. The equivalent strength of virginal concrete was 4.51MPa. From the result of Figure 6.3, the tensile strength of the recycled concrete RA1 is 10.3 percent higher than the control concrete strength. The tensile strength of RA2 is slightly lower than the natural concrete. This is because 14mm sized recycled aggregate was only used to make the new concrete and this may have caused more voids than in the RA1 mix. Based on the experimental results in both cases, the tests have shown that the RC can resist the high tensile stresses under loading.

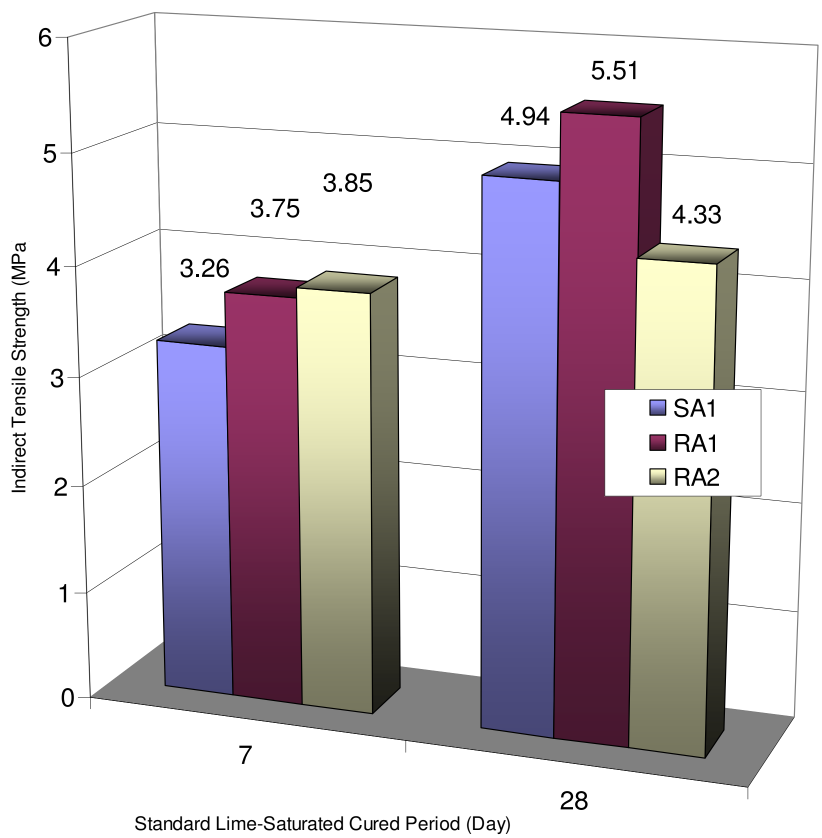


Figure 6.4 Indirect Tensile Strength Result

Figure 6.5 7-day Cylinder (14mm Recycled Aggregate)

broken by indirect tensile strength

Looking at Figure 6.5, the cylinder has fractured primarily in the cement mortar binding the aggregate. Most of the aggregate is intact, and has not fractured.

6.5 Modulus of Rupture Test Result and Analysis

The modulus of rupture is used to test the cracking strength/tensile strength of concrete which is an important parameter for determining deflection and minimum flexural reinforcement. The results of Figure 6.4 have showed that the bending strength of the non-reinforced recycled concrete beams has a slight difference compared with natural concrete beam. This is because 10mm sized aggregate had been used to make the natural concrete instead of 14mm sized aggregate as used in the RA in the recycled concrete.

Sample no	SA1-FL1	SA1-FL2	RA1-FL1	RA1-FL2
Date tested	31/08/06	31/08/06	31/08/06	31/08/06
Specimen age (Days)	30	30	30	30
Width at failure (mm)	100	100	101	101
Depth at failure (mm)	101	101	102	100
Span length (mm)	300	300	300	300
Strength (MPa)	7.2	6.3	5.6	5.3
Average strength (MPa)	6.8		5.5	

Table 6.6 Result of Flexure Strength

6.6 Drying Shrinkage of Concrete

The average of the final result of Figure 6.5 and 6.6 in 56-day sample is 815 micro-strain of recycled concrete and 810 micro-strain of natural concrete, which are very closes results in both cases for prevent deflection and are acceptable according to the Australian Standard AS3600.

Specimen number	RA1	RA2	SA1
Drying period (days)			
7	357	375	407
14	508	535	540
21	613	650	633
28	680	727	679
56	815	879	810

Table 6.7 Drying Shrinkage Result

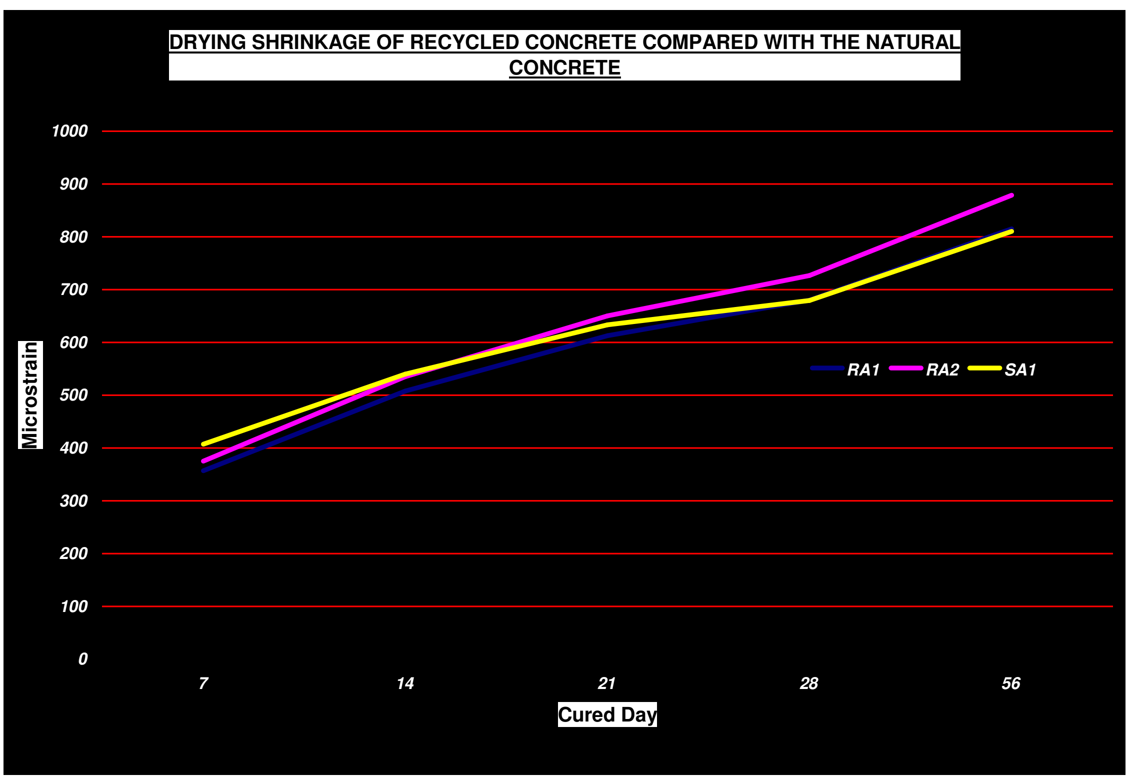


Figure 6.8 Drying Shrinkage Result

6.7 Static chord Modulus of Elasticity Test Result and Analysis

Figure 6.9 Result of Young Modulus

From the experimental results of Figure 6.7, the modulus of elasticity is 35555 MPa of natural concrete and 30196 of recycled aggregate. It was shown that there is only 17 percent difference between both types of concrete. According to the 6.1.2 of AS3600-2001, the modulus of Elasticity of recycled concrete can resist the material under long-term deformation.

6.8 Water Absorption and apparent volume of permeable voids Test Results and Analysis

Specimen number	RA1	SA1
Absorption after immersion (%)	9.22	6.54
Absorption after boiling (%)	9.63	6.79
Apparent Volume of Permeable Voids(%)	19.99	15.50

Table of 6.10 Result of Water Absorption and App. Vol. of Perm voids

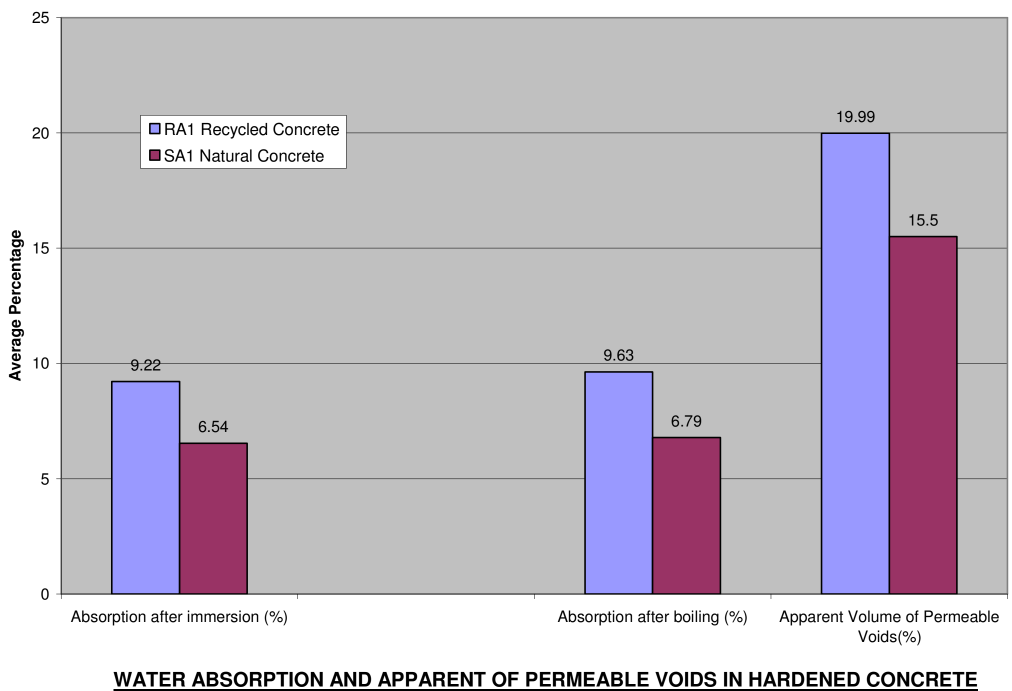


Figure 6.11 Result of Water Absorption and App. Vol. of Perm voids

There was approximately three percent difference between recycled and natural concrete with water absorption and apparent volume of permeable voids as shown in Figure 6.8 and 6.9. This was because the recycled aggregates are more porously than the natural aggregates; their pores are normally discontinuous in a concrete matrix, being completely enveloped by cement paste. Discrete voids or pores in concrete, including entrained air bubbles that are discontinuous similarly do not contribute significantly to concrete permeability.

Recycled concrete with a high proportion of disconnected pores may be less permeable that natural concrete with a much smaller proportion of continuous pores. However, the overall permeability of a concrete matrix would also depend on the size, distribution, interconnectivity, shape, and tortuosity of pores.

6.9 Rapid Chloride Permeability Test Results and Analysis

The result shown in Figure 6.10 and 6.11 showed that the total actual charge (in Coulombs) passed through the concrete cylinder is 906.8 and the maximum current recorded is 45mA in recycled concrete. Therefore, the Chloride Permeability is very low which is specified in the 700 to 1500 coulomb ranged of durability specifications for concretes tested at ages between 28 and 56 days of maturity. According to the results given below, the mixture of recycled concrete would provide high protection against chloride penetration and corrosion and would satisfy the corrosion protection criteria for reinforced concrete.

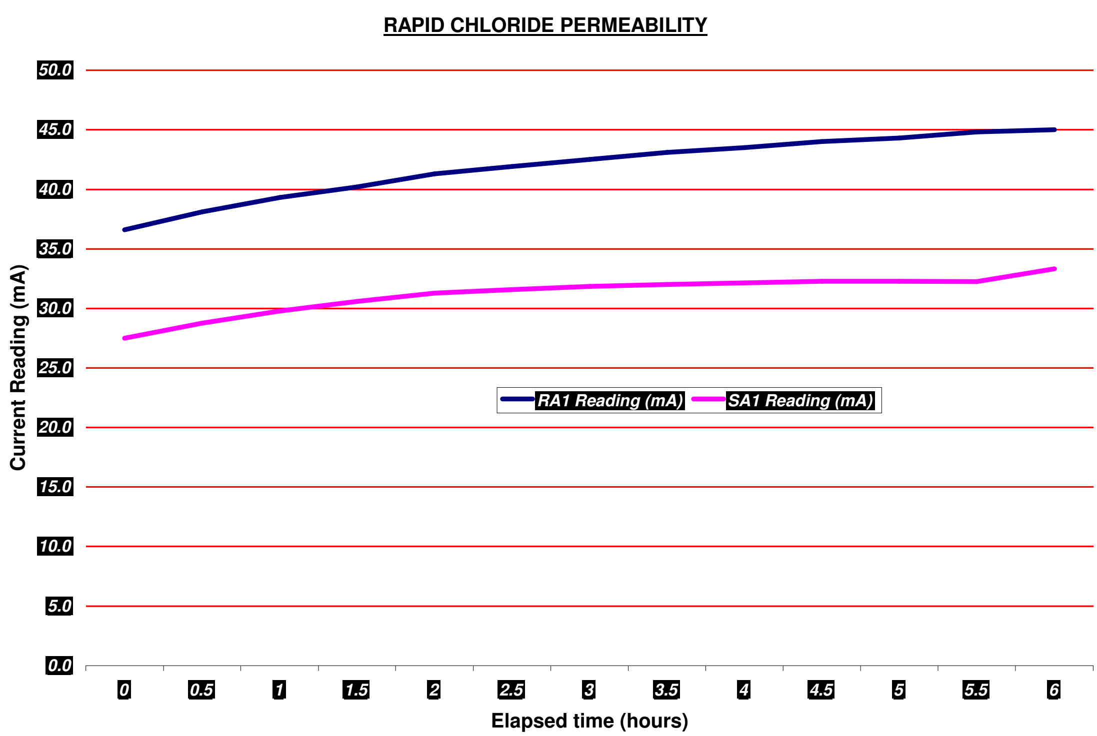


Figure 6.12 Result of Rapid Chloride Permeability

Sample Location (mm)	150-200	150-200
Maximum current record (mA)	45	32.33
Actual charge passed (Coulombs)	906.8	674.4
Charge passed, adjusted to standard sample size (Coulombs)	813.6	631.5
Chloride permeability	Very Low	Very Low
Sample	Recycled	Control
	50.7mm	52.6mm
Formed surface end	100.0 mm	

Table 6.13 Result of Rapid Chloride Permeability

6.10 Summary of Recycled Concrete

	Recycled Concrete (RA1)	Virginal Concrete (SA1)
Slump test (mm)	75	80
Workability	Good	Good
Compressive strength (MPa)	50.4	56
Splitting tensile strength (MPa)	5.51	4.94
Flexural strength (MPa)	5.45	6.75
Drying Shrinkage (Microstrain)	815	790
Modulus of Elasticity (MPa)	30223	35601
Water Absorption after boiling	9.63	6.79
Apparent volume of permeable voids	19.99	15.5
Rapid Chloride Permeability	very low	very low
Total Price per 10m3	$108.50	$121.40

Table 6.13 Summary of Result

Based on the experimental results shown in Table 6.12 as above, studies of hardened concrete properties, comprising bulk engineering properties (compressive cylinder strength, flexural strength, modulus of elasticity, drying shrinkage) and durability (water absorption and apparent volume of permeable voids, rapid chloride permeability) showed similar performance for RA and natural aggregate concrete mixes of equivalent strength.

6.11 Conclusions

6.11.1 The advantages of using recycled aggregate in structural concrete

- According to my results (refer to Figure 6.13), the cost of recycling can be up to $10.91 per ton to crush, as well as other expense. But by eliminating the cost of removing the old concrete and factoring in savings on disposal costs, it is possible to actually still save 10% by using the recycled aggregate around South East Queensland. This saving of 10% was based on low volumes of usage (such as my laboratory test), significant savings are possible with greater volumes of usage.
- The other most significant advantage is the reduced environmental impact by reducing the amount that must be disposed.
- Reduce demand for natural aggregates.
- Easy and convenience to transport the recycled aggregate within local area around South East Queensland.
- Create more jobs in the local workplace and also a financial benefit for business including Specifiers of road construction; Local council engineers; Concrete subcontractors; Specifiers of civil works; Demolition contractors; Recovered material processors and more.

6.11.2 The disadvantages of using recycled aggregate in structural concrete

The major concern is the variance of concrete strength with RC. The strength may differ from customer to customer & job to job. According to Queensland Recycling, the majority of the concrete received is from demolition work. The managers at Queensland Recycling estimate that the majority of this material was originally specified at 20MPa as a minimum. However, they advise that a sizable percentage of the material they receive would be lower than 20 MPa. Therefore there may be a risk of different compressive strengths each batch.

However, the laboratory tests of two different samples taken more than three months apart, the results showed the Particles Size Distribution, Water Absorption and particle density, Ten percent fines values and Wet/Dry Strength variation to be very similar for both samples. These results suggest that the local recycling plant is able to provided very consistent supplies at this point of time.

Chapter 7

Summary and Recommendations

7.1 Conclusion

According to a consultant from Queensland Recycling, and shown in the test carried out from multiple samples, it has bee shown that a supplier of recycled concrete aggregates can produce uniform quantity products to meet the specification of quality recycled aggregate and consistent supply.

There is also a significant argument that the laboratory test result showed that the compressive strength of recycled concrete can meet the requirements of high strength concrete standard. The results also indicated that the cost of recycled concrete were 10 percent less than those for natural concrete per m^3, as well as saving the budget for disposal.

This study has shown that recycled concrete aggregate is a useful resource and can be used in the production of high-strength or high-performance structural concrete subjected to the strength and durability tests, and had been shown to perform satisfactorily and in a comparable manner to concrete containing virgin aggregate. It is expected that this study could lead to a greater use of Recycled Concrete Aggregate materials and its diversion from landfills.

7.2 Achievement of Objectives

The achievement of the project as follows:

1. To achieve the compressive strength close to 50.0 MPa and showed that RCA is suitable to be used in structural concrete around South East Queensland.
2. The indirect tensile strength of recycled concrete was 4.94 MPa which is over that of natural concrete.
3. Confirmed that the costs of recycled concrete were 10 percent less than natural concrete per meter cube.
4. The results showed less than 0.1 percent contaminant in recycled aggregate and which is suitable for use in concrete.
5. As mention as above, the local recycling plant was able to supply consistent aggregate.
6. Based on the test results showed that durability and permeability properties of RCA were similar to those of concrete made with virgin aggregate.

7.3 Recommendations for Further Studies

The above results have showed that recycled aggregate may be used in structural concrete in the near future. Below are my recommendations for further studies as follows.

1. To build and test a reinforcing beam for future further work to determined if it can be used in structural beam by recycled concrete. The design of the reinforcing beam is below.

2. To investigate different batches with silica fume and superplasticizer to improve and achieve high strength concrete more than 60.0 MPa.

3. To prove the source and the grade of old concrete before recycling to assist clients overcoming barriers to use recycled aggregate in structural concrete.

4. To overcome water absorption and permeable voids problem and show RCA is the preferred option of Natural Aggregate for used in structural concrete.

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Appendix

Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project

PROJECT SPECIFICATION

FOR: Kwong Man Karen CHIU

TOPIC: THE USE OF RECYCLED CONCRETE AGGREGATE IN STRUCTURAL CONCRETE AROUND SOUTH EAST QUEENSLAND

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SPONSORSHIP: Department of MainRoads (Structural Division)

PROJECT AIM: The objectives of this project is to investigate the Engineering and durability properties for the use of recycled concrete aggregate in structural concrete compared with natural aggregate as well as the production process and quality of the recycled concrete aggregate around the South East Queensland to reduced environmental impact.

PROGRAMME: **Issue A, 17th March 2006**

1. Research the literature/information relating to the properties of Recycled Concrete Aggregate.
2. Research all the important issues of production in recycled concrete aggregate in particular South East QLD including Brisbane, Gold Coast, North Coast and Toowoomba.
3. Determine the sources of the concrete such as from general demolition waste or building demolition site.
4. Research the method and cost of transport and collection of concrete to be recycled.
5. The procedure for the production of good quality recycled concrete aggregate including the level of screening required, the type and capacity of the plant used for crushing.
6. Determine the treatment of "contamination" components of the demolition waste streams, such as plastics, plaster or gypsum, wood and metals has to be separately addressed.
7. Removal and cleaning of reinforcing steel to be re-sold as scrap.
8. Determine the levels of Quality/no. of grades that will be produced for example cleanliness and strength of the concrete.

9. Testing as required for low quality aggregate use in 20MPa concrete and for high quality aggregate use in 50MPa concrete or greater compared with natural aggregate.
10. Analyse the test results and evaluate the possible uses in the construction tasks.
11. Consultation with the industry for technical advice such as Queensland Recycling, Hansons Concrete, Wagner Concrete, Australian Cement and etc.

As time permits:

12. Testing Chloride/Sulphates/other contaminants in concrete from marine areas, to see the concrete saturated with salt (NaCl) would be acceptable into high quality concrete.
13. Testing the strength, creep and drying shrinkage for use in bridge concrete.
14. Research the cost of storing/classified different qualities of crushed concrete.
15. The overall economics of recycling costs more or less than normal/conventional concrete?
16. What are the advantages and disadvantages by using the Recycled Concrete Aggregate in Structural concrete?

AGREED: ____________________ (Student) ______________________ (USQ Supervisor)

Kwong Man Karen CHIU
(D98329913)
___/___/_____ (dated)

Dr. Qing Quan Stephen LIANG
___/___/_____ (dated)

Assessment of Consequential Effects

I have visited the local recycling company in Brisbane and other related industry companies such as Wagner Concrete and Hanson Concrete to interview their professional advisers. I found out that the local production plant achieved 95% cleanliness of the recycled aggregate and most concrete company do not feel comfortable in the use recycled aggregate to make the new concrete in Australia, even if it can be proved to have achieved the characteristic strength they preferred. I believe one of the reasons concrete companies are not willing to use recycled aggregate is because there is a plentiful supply of quarried (aggregates) in Australia and the price of recycled aggregate not much less expensive then natural aggregate.

If I can solve the cleanliness with consistence and the price problem of the recycled aggregate in Australia market and also find out the best way to achieve the high strength concrete in this project, this would reduce the environmental impact and save resources all over the world.

Project Methodology

My methodology is to find out the actual price of producing recycled aggregate including cost of transportation, laboratory testing and to compare them with natural aggregate. I also tried to prove what level of the quality of the recycled aggregate including the cleanliness and strength. That is why the most important issue is how I can achieve the strength of the new concrete by using recycled aggregate.

First, I will test the recycled aggregate provided by the local recycling company. For example, Particle Size Distribution of Aggregate, Particle Density and Water Absorption, Particle shape/Proportional Calliper, Wet/Dry Strength Variation, Los Angeles Abrasion, Sodium Sulphate Soundness, and Organic impurities other than sugar; to find out what is the mix design of trial specimen. Then I will try to make some cylinders to test the characteristic strength up to 50MPa to achieve the goal.

Safety Issues

There are some safety issues when I tried to carry out the experiments in the lab. I discovered that if there is too much dust around the environment this could cause health problems when sieving. If the person breaths too much dust for long period of time without suitable protection this could result in harm the lungs. The best way to address this issue is by wearing the dust-proof mask (N95 model) when sieving. The other safety issue related to this problem is there is the level of noise around the working area in laboratory when sieving which may damage the limb of the ears if you do not wear the correct hearing protection such as earmuffs or ear plug.

Another important safety issue to look at is there is always a need to carrying very heavy testing equipments and materials such as aggregate around the laboratory when performing the experiments as mention as above. If a person carries the material improperly or too much weight in one time, this may easily result in serious muscle damage or even breakage of bone that lead to injury, temporary or permanent.

A health hazard in the improper use of chemicals in the tests may results in toxins and dangerous exposure when heated in a fire situation and spilt into eyes or on skin. That why it is very important to wearing the right personal protective equipment such as dust-proof goggles and PVC or rubber gloves all the time when involves this type of work. Caution when using large quantities of chemical or if an inhalation risk exists, it is recommended that testers wear a coveralls and a Class P1 (particulate) respirator. It is also recommended that the chemicals always be stored in a cool, dry area, removed from foodstuffs and ensure containers are labelled, protected from physical damage and sealed when not in use.

I also need to highlight that there are many hidden hazards on the floor all around the laboratory that nobody can ever predict what may happen. This why it is highly recommended that anyone entered the laboratory should always wear safety shoes and suitable protection clothes all the time.

Resource Planning

The resource planning of my project is generally covered for three areas.

The recycled aggregate will be provided by the local recycling company and the natural aggregate will be sponsored by the Department of Mainroads.

The Laboratory equipments for the experiments on both the aggregate test and concrete strength test and most of the computer software including Microsoft word, Excel & Adobe Reader 7.0 are provide by department of Mainroads in Herston.

I am the person to running most of the aggregate test and Lorry will assist me to perform the concrete test.