University of Southern Queensland

Faculty of Engineering and Surveying

High-Strength Structural Concrete with Recycled Aggregates

A Dissertation Submitted By

Nelson, Shing Chai NGO

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Abstract

Recycled aggregates are comprised of crushed, graded inorganic particles processed from the materials that have been used in the constructions and demolition debris. The aim for this on – going project is to determine the strength characteristic of recycled aggregates for application in high strength structural concrete, which will give a better understanding on the properties of concrete with recycled aggregates, as an alternative material to coarse aggregate in structural concrete. The scope of this project is to determine and compare the high strength concrete by using different percentage of recycled aggregates.

The investigation was carried out using workability test, compressive test, indirect tensile test and modulus of elasticity test. There were total of eight batches of concrete mixes, consists of every 20% increment of recycled aggregate replacement from 0% to 100%. Moreover, 100% of recycled aggregate mix batches included fly ash, water/cement ratio of 0.36 and 0.43. The workability of concrete considerably reduced as the amount of recycled aggregate increased. This was evaluated through standard slump test and compacting factor test. For strength characteristics, the results showed that a gradually decreasing in compressive strength, tensile strength and modulus of elasticity as the percentage of recycled aggregate used in the specimens increased.

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NGO Shing Chai, Nelson

Student Number: D1230158

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Signature

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CHAPTER 1

INTRODUCTION

1.1 Introduction of Recycled Aggregate

Recycling is the act of processing the used material for use in creating new product. The usage of natural aggregate is getting more and more intense with the advanced development in infrastructure area. In order to reduce the usage of natural aggregate, recycled aggregate can be used as the replacement materials. Recycled aggregate are comprised of crushed, graded inorganic particles processed from the materials that have been used in the constructions and demolition debris. These materials are generally from buildings, roads, bridges, and sometimes even from catastrophes, such as wars and earthquakes.

Figure 1.1: Recycled Aggregate

1.2 Historical Background

The applications of recycled aggregate in the construction areas are wide and they had been used long time ago.

Wilmot and Vorobieff (1997) stated that recycled aggregate have been used in the road industry for the last 100 years in Australia. They also stated that the use of recycled aggregate for the construction and rehabilitation of local government roads has a great improve in the last five years.

C & D Recycling Industry (n.d.), the fact file stated that from the time of the Romans, the stones from the previous roads were reused when rebuilding their vaunted set of roads. It also stated that since the end of world war two, the recycling industry had been well established in Europe.

According to Seecharan (2004), the Detroid News stated that in 1980s, the old concrete crushed into a powder was a popular road builder at Michigan, USA.

1.3 Applications of Recycled Aggregate

Traditionally, the application of recycled aggregate is used as landfill. Nowadays, the applications of recycled aggregate in construction areas are wide. The applications are different from country to country.

- **Concrete Kerb and Gutter Mix**

Recycled aggregate have been used as concrete kerb and gutter mix in Australia. According to Building Innovation & Construction Technology (1999), Stone says that the 10mm recycled aggregate and blended recycled sand are used for concrete kerb and gutter mix in the Lenthall Street project in Sdyney.

Figure 1.2: Application of Recycled Aggregate as Road Kerb
(Source: Building Innovation & Construction Technology, 1999)

- **Granular Base Course Materials**

According to Market Development Study for Recycled Aggregate Products (2001), recycled aggregate are used as granular base course in the road construction. It also stated that recycled aggregate had proved that better than natural aggregate when used as granular base course in roads construction. They also found that when the road is built on the wet sub grade areas, recycled aggregate will stabilize the base and provide an improved working surface for pavement structure construction.

Figure 1.3: Recycled Aggregate used as Granular Base Course

(Source: Mehus and Lillestol (n.d))

- **Embankment Fill Materials**

Market Development Study for Recycled Aggregate Products (2001) stated that recycled aggregate can be used in embankment fill. The reason for being able to use in embankment fill is same as it is used in granular base course construction. The embankment site is on the wet sub grade areas. Recycled aggregate can stabilize the base and provide an improved working surface for the remaining works.

- **Paving Blocks**

Recycled aggregate have been used as paving blocks in Hong Kong. According to Hong Kong Housing Department (n.d.), recycled aggregate are used as typical paving blocks. A trial project had been started to test the long – term performance of paving blocks made with recycled aggregate in 2002.

Figure 1.4: Typical Paving Blocks

(Source: Hong Kong Housing Department, (n.d.))

- **Backfill Materials**

Recycled aggregate can be used as backfill materials. Mehus and Lillestol (n.d) found that Norwegian Building Research Institute (n.d) mentioned that recycled concrete aggregate can be used as backfill materials in the pipe zone along trenches after having testing in laboratory.

Figure 1.5: Recycled Aggregate as Backfill Materials
(Source: Mehus and Lillestol (n.d))

- **Building Blocks**

Recycled aggregate used as building blocks. Mehus and Lillestol (n.d) stated that Optiroc AS had used recycled aggregate to produce the masonry sound insulation blocks. The masonry sound insulation blocks that produced had met all the requirements during the laboratory testing.

Figure 1.6: Recycled Aggregate used as Building Blocks
(Source: Mehus and Lillestol (n.d))

1.4 International Status

Mehus and Lillestol (n.d.) stated that RESIBA had constructed a new high school in Sorumsand, outside the city of Oslo, Norway in 2001. Recycled concrete aggregate had been used in this project. Thirty – five percent of coarse aggregate were replaced by recycled concrete aggregate in the foundations, half of the basement walls and columns. Several tests were conducted based on fresh and hardened concrete properties and the results shown that the concrete with thirty – five percent of recycled concrete aggregate have good freeze – thaw resistance. The use of recycled concrete aggregate did not shown any noticeable increase in cracking.

Figure 1.7: Construction of the New High School in Sorumsand, Oslo, Norway (Source: Mehus and Lillestol (n.d))

According to Grubl, Nealen and Schmidt (n.d.), there is a building project, the "Waldspirale" by Friedensreich Hundertwasser, made from concrete with recycled aggregate in Darmstadf from November 1998 to September 1999. Numerous tests were evaluated for freshly missed and also hardened concrete properties. The result shown that the consistency controlled method for concrete with recycled aggregate is applicable. And it leads to concrete of equal quality when compared with concrete made from natural aggregate.

According to Regain (1993/94), recycled aggregate were used as capping and sub-base layers in housing development at North Bracknell, UK in 1993/94. Visual inspections and condition surveys were carried out by using the falling weight deflectometer in 1998. The result shown that the sections with recycled aggregate did not show any difference in appearance compared to the sections that using natural aggregate. The tests gave the larger values of elastic modulus in the recycled aggregate sections.

According to Regain (2001), footway paving slabs are being replaced gradually in London Borough of Bexley. Recycled aggregate are used as coarse aggregate in the concrete mix with a 12:1 aggregate to cement mix.

1.5 Advantages

There are many advantages through using the recycled aggregate. The advantages that occur through usage of recycled aggregate are listed below.

- **Environmental Gain**

The major advantage is based on the environmental gain. According to CSIRO (n.d.), construction and demolition waste makes up to around 40% of the total waste each year (estimate around 14 million tones) going to land fill. Through recycled these material, it can keep diminishing the resources of urban aggregated. Therefore, natural aggregate can be used in higher –grade applications.

- **Save Energy**

The recycling process can be done on site. According to Kajima Technical Research Institute (2002), Kajima is developing a method of recycling crushed concrete that used in the construction, known as the Within-Site Recycling System. Everything can be done on the construction site through this system, from the process of recycled aggregate, manufacture and use them. This can save energy to transport the recycled materials to the recycling plants.

- **Cost**

Secondly is based on the cost. The cost of recycled aggregate is cheaper than virgin aggregate. According to PATH Technology Inventory (n.d.), the costs of recycled concrete aggregateare sold around \$3.50 to \$7.00 per cubic yard. It depends on the aggregate size limitation and local availability. This is just around one and half of the cost for natural aggregate that used in the construction works. The transportation cost for the recycled aggregate is reduced due to the weight of recycled aggregate is lighter than virgin aggregate. Concrete Network (n.d) stated that recycling concrete from the demolition projects can saves the costs of transporting the concrete to the land fill (around $0.25 per ton/ mile), and the cost of disposal (around $100 per ton). Beside that, Aggregate Advisory Service (n.d.) also state that the recycling site may accept the segregates materials at lower cost than landfill without tax levy and recycled aggregate can be used at a lower prices than primary aggregate in the construction works.

- **Job Opportunities**

There will be many people involved in this new technology, such as specialized and skilled persons, general workers, drivers and etc. According to Scottish Executive (2004), a Scottish Market Development Program is developed. The purpose of this program is to recycle the materials that arising in Scotland. This program will provide 150 new jobs in the Scottish industry.

- **Sustainability**

The amount of waste materials used for landfill will be reducing through usage of recycled aggregate. This will reduce the amount of quarrying. Therefore this will extend the lives of natural resources and also extend the lives of sites that using for landfill.

- **Market is Wide**

The markets for recycled concrete aggregate are wide. According to Environmental Council of Concrete Organization (n.d), recycled concrete aggregate can be used for sidewalk, curbs, bridge substructures and superstructures, concrete shoulders, residential driveways, general and structural fills. It also mentioned that recycled concrete aggregate can be used in sub bases and support layers such as unstabilized base and permeable bases.

1.6 Disadvantages

Although there are many advantages by using recycled aggregate. But there are still some disadvantages in recycled aggregate.

- **Hard to have permit**

Jacobsen (1999) stated that it is hard to get the permit for the machinery that needed air permit or permit to operate during the recycling process. These has to depend on the local or state regulations whether this technology is implemented or not.

- **Lack of Specification and Guidelines**

According to Kawano (n.d), there is no specification or any guideline when using recycled concrete aggregate in the constructions. In many cases, the strength characteristic will not meet the requirement when using recycled concrete aggregate. Therefore, more testing should be considered when using recycled concrete aggregate.

- **Water Pollution**

The recycled process will cause water pollution. Morris of National Ready Mix Concrete Association (n.d) had mentioned that the wash out water with the high pH is a serious environmental issue. According to Building Green (1993), the alkalinity level of wash water from the recycling plants is pH12. This water is toxic to the fish and other aquatic life.

1.7 Project Aim

The aim for this on – going project is to determine the strength characteristic of recycled aggregate for application in high strength structural concrete, which will give a better understanding on the properties of concrete with recycled aggregate, where can be an alternative material to coarse aggregate in structural concrete.

1.8 Project Scope

The scope of this project:

- Review and research of recycled aggregate.
- Construct the concrete specimens by using different percentage of recycled aggregate.
- Investigation and laboratory testing on high strength concrete with recycled aggregate.
- Analysis the results and recommendation for further research area.

1.9 Dissertation Overview

This dissertation is structured in the following format.

- Chapter 2 provides a review of relevant literature, overview of recycling process, as well as comparison of recycled aggregate and natural aggregate. This chapter also discussed the previous investigation and testing done with recycled aggregate.

- Chapter 3 includes the preliminary design and information on the recycled aggregate testing, sieve analysis and design of the concrete mix.

- Chapter 4 describes the experimental methodology carried out in order to obtain the required data.

- Chapter 5 discusses the results and analysis of all experimental results obtained from the testing procedures.

- Chapter 6 contains the conclusions of the research and recommendations on further work.

Chapter 2

Review of Recycled Aggregate

2.1 Literature Review of Recycled Aggregate

The applications of recycled aggregate in the construction area are very wide. There are many testing based on the recycled aggregate have been carried out all around the world. Hanson and Torben (1986) stated that since 1945, the research on recycled aggregate had been carried out in many countries. Some of the literature reviews on recycled aggregate are shown as below.

The main aim that testing the recycled aggregate is to find out the result of the strength characteristic on it and analysis whether recycled aggregate is suitable to apply in the construction area. According to Rammamurthy and Gumaster (1998), the compressive strength of recycled aggregate concrete was relatively lower and variation was depended on the strength of parent concrete from the obtained aggregate.

Limbachiya and Leelawat (2000) found that recycled concrete aggregate had 7 to 9% lower relative density and 2 times higher water absorption than natural aggregate. According to their test results, it shown that there was no effect with the replacement of 30% coarse recycled concrete aggregate used on the ceiling strength of concrete. It also mentioned that recycled concrete aggregate could be used in high strength concrete mixes with the recycled concrete aggregate content in the concrete.

Sagoe, Brown and Taylor (2002) stated that the difference between the characteristic of fresh and hardened recycled aggregate concrete and natural aggregate concrete is relatively narrower than reported for laboratory crush recycled aggregate concrete mixes. There was no difference at the 5% significance level in concrete compressive and tensile strength of recycled concrete and control normal concrete made from natural aggregate.

In the same year, poon (2002) reported that there were not much effect of the compressive strength of brick specimens with the replacement of 25% and 50% of recycled aggregate. But when the percentage of recycled aggregate replacement increased, the compressive strength of the specimens was reducing. Mandal, Chakarborty and Gupta (2002) also found that there will no effects on the concrete strength with the replacement of 30% of recycled aggregate. But the compressive strength was gradually decreasing when the amount replacement of recycled increased. They concluded that the properties and the strength characteristic of recycled aggregate concrete were deficiency when compared to the specimens that made by the natural aggregate.

Limbachiya (2003) found that there is no effect by using up to 30% of coarse recycled concrete aggregate on the standard 100mm concrete cube compressive strength. But when the percentage of recycled concrete aggregate used increased, the compressive strength was reducing.

From the literature review shown, the results of the compressive strength are all reducing when the replacement of recycled aggregate used in the concrete increased. There must be some influences that cause the reducing of compressive strength of recycled aggregate. According to Tavakoli (1996), the strength characteristics of recycled aggregate concrete were influenced by the strength of the original concrete, the ratio of coarse aggregate to fine aggregate in the original concrete, and the ratio of top size of the aggregate in the original concrete in the recycled aggregate. He also mentioned that water absorption and Los Angeles abrasion loss will influence the water cement ratio and top size ratio for the strength characteristic of recycled aggregate.

Bodin and Zaharieva (2002) stated that decreasing of the strength of recycled concrete specimen was due to the increase of water/cement ratio that required by the preservation of workability.

There are some methods used to improve the strength of the recycled aggregate. Kantawong and Laksana (1998) mentioned that the fineness modulus and percentage of water absorption used instead with the recycled aggregate is higher than natural aggregate. The results of compressive strength of added reduce water admixture concrete is higher than the one that not added reduce water admixture concrete, ane the compressive strength of concrete produced that using recycled aggregate is higher than concrete using natural coarse aggregate.

Sawamoto and Takehino (2000) found that the strength of the recycled aggregate concrete can be increased by using Pozzolanic material that can absorb the water.

Mandal (2002) stated that adjusted the water/cement ratio when using recycled concrete aggregate during the concrete mixing can improved the strength of the recycled aggregate concrete specimens. From the obtained result, recycled aggregate concrete specimens had the same engineering and durability performance when compared to the concrete specimens made by natural aggregate within 28days design strength.

Chen and Kuan (2003) found that the strength of the concrete specimens was affected by the unwashed recycled aggregate in the concrete. The effect will more strange at the low water cement ratio. These effects can be improved by using the washed recycled aggregate.

Another improving method is using the sly ash in the recycled aggregate mixing. Mandal (2002) stated that application of fly ash in the recycled concrete aggregate had improved the durability of the recycled aggregate concrete. Poon (2002) also mentioned that the use of fly ash could improve the strength characteristic of recycled aggregate. He stated that the compressive strength of concrete paving blocks was reached 49MPa at 28days by using fly ash. Berry and Malhotra (1980) stated that for high strength concrete, fly ash functions by providing increased strength at late ages of curing (56 to 91 days) that cannot be achieved through the use of additional Portland cement.

Some precautions must be taken while using recycled aggregate in the concrete mixing. According to Bodin and Zaharieva, the precautions must be taken was because of there were some pathological reactions such as alkali – aggregate reaction and sulphate reaction may be include in the performed characterisation of industrially produced recycled aggregate. They also mentioned that the mix proportioning of recycled aggregate concrete must be suited when both fine and coarse recycled aggregate were substituted for natural aggregate.

2.2 Review on Recycled Process

This section discusses the recycling process and method.

2.2.1 Recycling Plant

Recycling plant normally located in the suburbs of cities due to the noise pollution that make by the equipments that used during recycling process. According to Aggregate and Quarry (n.d.), all the machinery used have to fit with the effective mufflers to reduce the noise from the processing activity.

2.2.2 Sources of Recycled Aggregate

Traditionally, Portland concrete aggregate from the demolition construction are used for landfill. But nowadays, Portland concrete aggregate can be used as a new material for construction usage.

According to Recycling of Portland Cement Concrete (n.d), recycled aggregate are mainly produced from the crushing of Portland concrete pavement and structures building. It stated that the isolated areas of 1 inch of asphalt concrete can be used to produce the recycled aggregate. The main reason that choosing the structural building as the source for recycled aggregate is because there is a huge amount of crushed demolition Portland cement concrete can be produced.

2.2.3 Equipments used during Recycling Process

The equipments that used during recycling process are various from the site conditions and also country to country. There are few different types of equipment had been used effectively to break up the Portland cement pavement and structural building.

2.2.3.1 Portland Cement Pavement

Recycling of Portland Cement Concrete (n.d) mentioned that there are few different types of equipment had been used for crushing the Portland cement pavement. The equipments are as below:

(1) ***Diesel pile – driving hammer***. It is mounting on a motor grader that sticks in the Portland cement pavement on around 30cm grid pattern.

Figure 2.1: Diesel Pile – Driving Hammer

(Source: Recycling of Portland Cement Concrete, (n.d))

(2) ***Rhino – horn – tooth – ripper – equipped hydraulic excavator***. It is used to remove all the steel reinforcement that remaining in the Portland cement pavement.

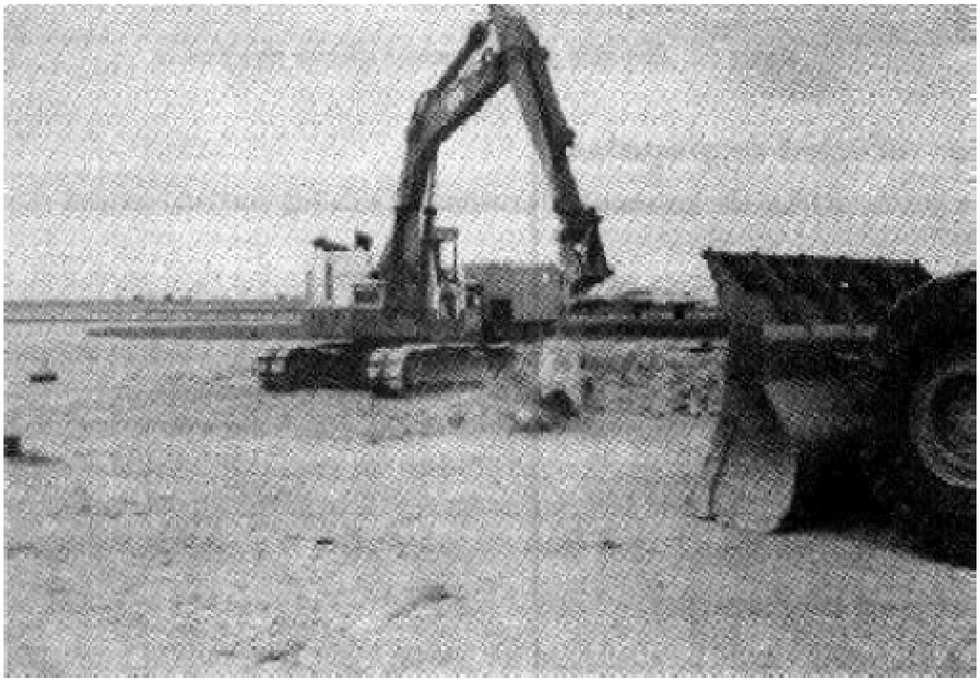

Figure 2.2: Rhino – horn – tooth – ripper – equipped Hydraulic Excavator
(Source: Recycling of Portland Cement Concrete, (n.d))

2.2.3.2 Structural Building

Hong Kong Building Department (n.d) mentioned that the following methods had been used to crush the structural building.

(1) ***Mechanical by hydraulic crusher with long boom arm***. The concrete and steel reinforcements are broken by the crusher through the long boom arm system. This method is suitable for the dangerous buildings.

Figure 2.3: Hydraulic Crusher with Long Boom Arm
(Source: Hydraulic Circuit Technology, 2000)

(2) ***Wrecking ball***. The building is demolished by the impact energy of the wrecking ball which suspended from the crawler crane.

Figure 2.4: Wrecking Ball
(Source: The Trading Tribe, 2003)

(3) ***Implosion***. A design included pre – weakening of the structure, the placement of the explosives and the building collapse in a safe manner have to develop.

Figure 2.5: Kingdome Implosion
(Source: Davinel, 2000)

2.2.4 Transportation

After the structural buildings and Portland cement pavements are demolished, the concrete debris has to send to the recycling plants for processing. Construction and Demolition Waste Recycling Information (n.d.) mentioned that it is good to use the roll – off containers or large dump body trailers to transport the mixed load of construction and demolition debris. This is the most effective and cost effective means of the transportation. It also mentioned that the construction and demolition debris can be transport by the closed box trailers and covered containers.

Figure 2.6: Roll – off Container

(Source: On – site Disposal Facility, 2000)

2.2.5 Crushing Plant

Crushing is the initial process of producing the construction and demolition debris into recycled aggregate. The concrete debris is crushed into pieces in this process. Aggregate and Quarry (2001) stated that generally the equipments used for crushing process are either jaw or impacted mill crushers. It also stated that all the recycling crushers have a special protection for conveyor belts to prevent damage by the reinforcement steel that in the concrete debris. They are fitted with the magnetic conveyors to remove all the scrap metal.

According to Recycling of Portland Cement Concrete (n.d.), the equipments used to crush and size the existing concrete have to include the jaw and cone crushers. The concrete debris will break down to around 3 inches by the primary jaw crusher. It also mentioned that the secondary cone crushers will breaks the materials to the maximum size required which vary between ¾ and 2 inches.

Figure 2.7: Load into Primary Crusher

(Source: Boral, 2002)

During the crushing process, all the reinforcing steels have to remove away. Professor S L Bakoss and Dr R Sri Ravindarajah (1999) stated that there are three methods of sorting and cleaning the recycled aggregate, which are electromagnetic separation, dry separation and wet separation. Electromagnetic separation process is removal of reinforcing steel by the magnet that fitted across the conveyor belt in the primary and secondary crushers. Dry separation process is removing the lighter particles from the heavier stony materials by bowing air. This method always causes lot of dust. Wet separation process is the aquamator, which the low density contaminants are removed by the water jets and float – sink tank, and this will produces very clean aggregate.

According to COST 337 Unbound Granular Materials for Road Pavements (n.d.), the wood pieces that contained in the concrete debris can be removed by hand – picking from a special platform over the discharge conveyor.

After finish the crushing process, the materials are then sent to the screening plant.

Figure 2.8: Electromagnetic Separation Process
(Source: Boral, 2002)

Figure 2.9: Picking Shed
(Source: Boral, 2002)

Figure 2.10: Wet Separation Process (Aquamator)
(Source: Boral, 2002)

2.2.6 Screening Plant and Washing Plant

Screening is the process that separates the various sizes of recycled aggregate. The screening plant is made of a series of large sieves separates the materials into the size required.

Recycling of Portland Cement Concrete (n.d.) stated that the size of screen that used to separate the coarse recycled concrete aggregate and fine recycled aggregate is 3/8 inch. The size of screen used to separate the coarse recycled aggregate can be under or over ¾ inches. It also stated that one more screen should be used to separate those particles that more than the specified size.

After the screening process, the recycled are then sent to the washing plant. COST 337 Unbound Granular Materials for Road Pavements (n.d.) stated that the recycled aggregate that produced have to be very clean when using in the high quality product situation.

Figure 2.11: Screening Plant
(Source: R. R. Equipment Company, 2003)

Figure 2.12: Washing Plant
(Source: R. R. Equipment Company, 2003)

2.2.7 Stockpile

After all the recycling process, recycled aggregate are stored in the stockpile and ready to use. All the recycled aggregate are stored according to the different size of aggregate. According to Recycling of Portland Cement Concrete (n.d.), the stockpile has to prevent from the contamination of foreign materials. It also mentioned that the vehicles used for stockpiling have to be kept clean of foreign materials.

Figure 2.13: Stockpile
(Source: Boral, 2002)

Figure 2.14: Load Out and Sales

(Source: Boral, 2002)

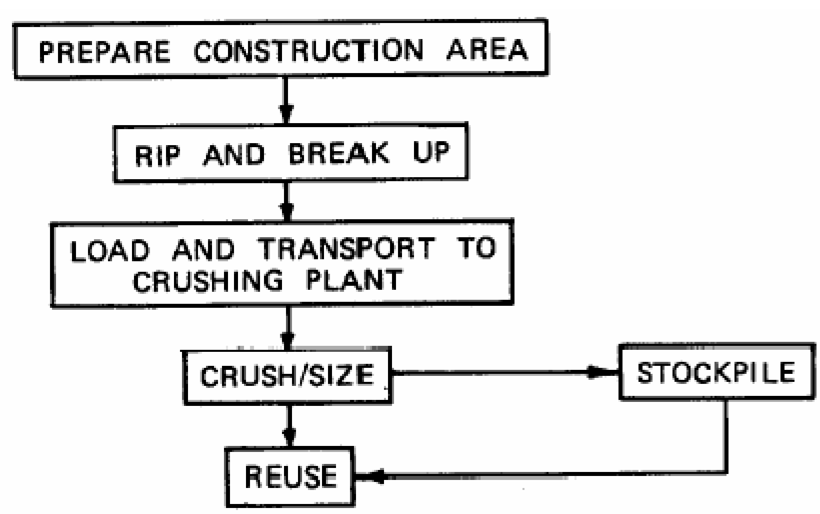

Figure 2.15: Recycling Portland Cement Concrete Flow Chart

(Source: Recycling of Portland cement concrete, (n.d))

2.3 Comparison of Recycled Aggregate and Natural Aggregate

- **Texture**

Recycled aggregate has the rough – textured, angular and elongated particles where natural aggregate is smooth and rounded compact aggregate.

According to Portland Cement Association (n.d.), the properties of the freshly mixed concrete will be affected by the particle shape and surface texture of the aggregate. The rough – texture, angular and elongated particles require much water than the smooth and rounded compact aggregate when producing the workable concrete. The void content will increase with the angular aggregate where the larger sizes of well and improved grading aggregate will decrease the void content.

Natural Aggregate **Recycled Aggregate**

Figure 2.16: Comparison between Natural Aggregate and Recycled Aggregate

- **Quality**

The quality is different between recycled aggregate and recycled aggregate. According to Sagoe and Brown (1998), the quality of natural aggregate is based on the physical and chemical properties of sources sites, where recycled aggregate is depended on contamination of debris sources. It also stated that natural resources are suitable for multiple product and higher product have larger marketing area, but recycled aggregate have limited product mixes and the lower product mixes may restrain the market.

- **Density**

The density of the recycled concrete aggregate is lower than natural aggregate. Sagoe and Brown (1998) stated that when compare with natural aggregate, recycled concrete aggregate have lower density because of the porous and less dense residual mortar lumps that is adhering to the surfaces. When the particle size is increased, the volume percentage of residual mortar will increase too.

- **Strength**

The strength of recycled aggregate is lower than natural aggregate. Sagoe and Brown (1998) stated that this is due to the weight of recycled aggregate is lighter than natural aggregate. This is the general effect that will reduce the strength of reinforcement concrete. Further discussion on the strength of recycled aggregate will be mentioned in chapter 5.

- **Location**

Natural aggregate are derived from a variety of rock sources. The processing plant for natural aggregate depends on the resource. It usually occurs at the mining site and outside the city.

Recycled aggregate are derived from debris of building constructions and roads. The locations of recycling plants are depended on where the structures are demolished. The recycling process is often located in the urban area.

Chapter 3

Properties and Testing of Aggregate

3.1 Particle Density and Water Absorption of Course and Fine Aggregate

Particle density is one of the important factors that used to determine the properties of aggregate. It is required when calculate the mix design for concrete. Australian Standard HB64 (2002) stated that in the concrete mix, substituting different density of aggregate would influence the yield, unit mass of concrete and quality of aggregate needed for a concrete volume. The particle density of aggregate is generally affected by the amount of moisture present and the geological properties of aggregate. In this project, particle density of aggregate was carried out to determine the volume and weight of aggregate needed for the concrete mixes. The determination of particle density was according to AS1141.5 and AS1141.6.1.

Water absorption is the amount of moisture absorbed in the aggregate. The water absorption capacity is based on saturated surface dry condition and oven dried condition. Australian Standard HB64 (2002) mentioned that the amount of water in a concrete mix has direct effect on the setting time and compressive strength of concrete. It also stated that moisture content of the aggregate had to determine first before preparing a mix design for a particular aggregate. If the moisture content of the concrete is not met the target, then more water have to add to avoid a loss of workability. If the moisture content exceeds the target, then less water should be added. The determination of water absorption of aggregate was according to AS1141.5 and AS 1141.6.1.

In this project, determination of particle density and water absorption of aggregate were based on natural aggregate with grain size of 20mm, 10mm and 7mm, recycled aggregate with gain size of 14mm and 5mm, and fine aggregate (sand). All the testing was carried out in the engineering laboratory of University of Southern Queensland.

3.1.1 Apparatus and Test Procedure of Course Aggregate

The following apparatus and equipments used were complied with AS1141.2.

1. **Wire Basket**: With a suitable mesh and size, and with wire hangers for suspended it from the balance.

2. **Water Bath**: Appropriate size and shape to locate the basket and give a cover of at least 50mm water above the top of the immersed basket.

3. **Balance**: Sufficient capacity with a limit performance that not more or less than 5g and have a type which can locate a basket that containing the sample to be suspended from it and weight in the water.

4. **Oven**: Thermostatically controlled that gives a temperature of 105ºC to 110ºC.

5. **Container**: Suitable size for putting the sample.

6. **Towels and Dry Cloths**: To dry the surface of aggregate.

7. **Dishes**: Suitable Sizes.

The test procedure was according to AS1141.6.1 – 2000. The procedures were as below:

1. Immersed the aggregate in the water at room temperature with the 20mm height of water above the top of aggregate. The aggregate was stirred occasionally to dislodge the air bubbles. The aggregate was immersed for one day (24hours).

2. The aggregate was transferred to the basket and immersed in the water contained in a bath below the balance. The basket was jiggled to dislodge the air bubbles. Then, attached the basket hanger to the balance. The basket and aggregate in the water was weighted and recorded.

3. The basket and aggregate was then removed from the water and let them to drain. All the aggregate was transferred to a dish. The aggregate was dried out after determined the particle density and water absorption.

4. The empty basket was put into the water bath and jiggled to dislodge the air bubbles. The basket was weighted in the water to the nearest 1g and recorded.

5. Surface dried the aggregate by rolling on a dry cloth. The aggregate was spread one stone deep over a dry cloth and allowed it to surface dry. Continue drying until all visible films of water had been removed but the surface of aggregate still damp.

6. The aggregate was dried in the oven at the temperature of 105ºC to 110ºC to get the constant mass.

3.1.2 Apparatus and Test Procedure of Fine Aggregate

The following apparatus and equipments used were complied with AS1141.2.

1. **Metal Mould**: 0.88mm sheet metal, truncated cone shape, 75mm height with diameter of 90mm decrease to 38mm diameter.

2. **Balance**: Sufficient capacity with a limit performance that not more or less than 5g.

3. **Tamping Rod**: A flat circular tamping face with 25mm diameter.

4. **Oven:** Thermostatically controlled that gives a temperature of 105ºC to 110ºC.

5. **Container:** Suitable size for putting the sample.

6. **Glass Container and Flask**: 400mm diameter and 600mm height glass container to contain water and a flask of 500mL volumetric flask with a lid.

7. **Heater or Drier**: Provide gentle flow of warm air.

8. **Dishes**: Suitable sizes.

The test procedure was according to AS1142.5. The procedures were as below:

1. Immersed the sand in the water at room temperature for a period (24hours). The aggregate was stirred to dislodge the air bubbles.

2. Drained off the water and the sand was spread on a flat impervious surface. Dried the sand surface by exposing to a moving current of warm air. Stirred it regularly until uniform dried. The sand can also dry under the sun for few hours.

3. Filled the sand into a conical mould. Tamped the surface of sand with tamping tool (25 times). Conical mould was lift vertically. The cone of sand will retain it shape if free moisture presented. Added more water if the sand was too dry.

4. Continued drying with constant stirring. Repeated step 3 until the cone of sand slump on the removal of the mould. This mean the sand had reached saturated dry condition. Weighted and recorded the mass of sand.

5. The sand was placed into a volumetric flask and filled in the water. Weighted and recorded the mass of sand, flask and water.

6. Removed the sand from the flask without loosing any particle into a container. Filled the water into the flask. Weighted and recorded the mass of flask and water.

7. The sand was dried in the oven at the temperature of 105ºC to 110ºC. Weighted and recorded the mass of sand after 24 hours.

Figure 3.1: Balance for Aggregate Weighting.

Figure 3.2: Thermostatically Controlled Oven.

3.1.3 Result and Analysis

Table 3.1: Weight of course aggregate in the test.

Types and size of aggregate	Natural 20mm	Natural 10mm	Natural 7mm	Recycled 14mm	Recycled 5mm
A, Mass of oven dried aggregate (g)	1445.0	1482.7	1724.5	1133.6	1308.4
B, Mass of SSD aggregate (g)	1463.2	1502.6	1751.8	1196.7	1388.7
C, Mass of aggregate and wire basket in water (g)	1097.6	1125.7	1292.0	846.6	949.1
D, Mass of wire basket in water (g)	135.0	135.0	133.3	133.5	133.5

- 20mm Natural Aggregate

Bulk Density (dry) $= \dfrac{A \times 1000}{D - (C - B)}$

$= 2886.54 \text{ kg/m}^3$

Bulk Density (dry) $= \dfrac{B \times 1000}{D - (C - B)}$

$= 2922.89 \text{ kg/m}^3$

Bulk Density (dry) $= \dfrac{(B - A) \times 100}{A}$

$= 1.26\ \%$

- 10mm Natural Aggregate

Bulk Density (dry) $= \dfrac{A \times 1000}{D - (C - B)}$

$= 2896.46 \text{ kg/m}^3$

Bulk Density (dry) $= \dfrac{B \times 1000}{D - (C - B)}$

$= 2935.34 \text{ kg/m}^3$

Bulk Density (dry) $= \dfrac{(B - A) \times 100}{A}$

$= 1.34\ \%$

- 7mm Natural Aggregate

Bulk Density (dry) $= \dfrac{A \times 1000}{D - (C - B)}$

$= 2907.60 \text{ kg/m}^3$

Bulk Density (dry) $= \dfrac{B \times 1000}{D - (C - B)}$

$= 2953.63 \text{ kg/m}^3$

Bulk Density (dry) $= \dfrac{(B - A) \times 100}{A}$

$= 1.58 \%$

- 14mm Recycled Aggregate

Bulk Density (dry) $= \dfrac{A \times 1000}{D - (C - B)}$

$= 2344.09 \text{ kg/m}^3$

Bulk Density (dry) $= \dfrac{B \times 1000}{D - (C - B)}$

$= 2474.57 \text{ kg/m}^3$

Bulk Density (dry) $= \dfrac{(B - A) \times 100}{A}$

$= 5.57 \%$

- 5mm Recycled Aggregate

$$\text{Bulk Density (dry)} = \frac{A \times 1000}{D - (C - B)}$$

$$= 2283.02 \text{ kg/m}^3$$

$$\text{Bulk Density (dry)} = \frac{B \times 1000}{D - (C - B)}$$

$$= 2423.14 \text{ kg/m}^3$$

$$\text{Bulk Density (dry)} = \frac{(B - A) \times 100}{A}$$

$$= 6.14\ \%$$

Table 3.2: Weight of fine aggregate in the test.

Description	Fine aggregate (sand)
A, Mass of dry aggregate	71.0g
B, Mass of SSD aggregate	77.3g
C, Mass of flask, aggregate and water	384.4g
D, Mass of flask and water	340.4g

- Fine Aggregate (sand)

$$\text{Bulk Density (dry)} = \frac{A \times 1000}{D - (C - B)}$$

$$= 2123.13 \text{ kg/m}^3$$

$$\text{Bulk Density (dry)} = \frac{B \times 1000}{D - (C - B)}$$

$$= 2321.32 \text{ kg/m}^3$$

$$\text{Bulk Density (dry)} = \frac{(B - A) \times 100}{A}$$

$$= 4.01 \%$$

Table 3.3: Result of particle density and water absorption of all aggregate.

Types and Size of Aggregate	Particle Density (Dry), kg/m^3	Particle Density (SSD), kg/m^3	Water Absorption, %
20mm natural aggregate	2886.54	2922.89	1.26
10mm natural aggregate	2896.46	2935.34	1.34
7mm natural aggregate	2907.60	2953.63	1.58
14mm recycled aggregate	2344.09	2474.57	5.57
5mm recycled aggregate	2283.02	2423.14	6.14
Fine aggregate (sand)	2132.13	2321.32	4.01

The results shows that fine aggregate has lower density than natural aggregate and recycled aggregate. There is a difference of 25% among fine aggregate and natural aggregate. And 5% difference between fine aggregate and recycled aggregate. From the result, the density of recycled aggregate is lower than natural aggregate. The average particle density of natural aggregate is 2900kg/m^3 but average particle density of recycled aggregate is only 2300kg/m^3. This mean recycled aggregate is lighter than natural aggregate.

The water absorption capacity of recycled aggregate is higher than natural aggregate and fine aggregate. The average water absorption rate of recycled aggregate is around 6%, but water absorption rate of natural aggregate is only 1.4% and fine aggregate is 4%. This shows that water absorption of recycled aggregate is around 4 times of natural aggregate and 1.5 times of fine aggregate. This result shows that more water needed to be added when using recycled aggregate in the concrete mixing to get an acceptable workability.

3.2 Sieve Analysis

Sieve analysis is used to find the amount of different size of aggregate used in a concrete mix. It is carried out to let the aggregate pass through a series of sieves. The sieve analysis can be done either by hand or sieve machine. It is recommended that using sieve machine will give more accurate result and can use several sieves in one time.

The aggregate was air – dried before carried out the sieve analysis. According to Neville (1997), this is to avoid lumps of fine particles being classified as large particles and prevent clogging of the finer sieves. A method called ‘sample reduction’ was carried out, where the amount of aggregate was reduced from bucket by riffling. The aggregate was discharged in the riffle and collected in two boxes at the bottom of the chutes. One box was discharge and the other box was riffled repeatedly until met the specification. Determination of the sieve analysis was according to AS1141.11.

In this project, sieve analysis was carried out base on course aggregate and fine aggregate. The sieve sizes for course aggregate was from 19mm to 1.18mm and sieve sizes for fine aggregate was from 2.36mm to 75μm.

3.2.1 Apparatus and Test Procedure of Sieve Analysis

The following apparatus and equipments used were complied with AS1141.2

1. **Balance**: Sufficient capacity with a limit performance that not more or less than 5g of weight.

2. **Sieves**: Test sieves that complied with AS1152.

3. **Brush:** With soft and fine broom.

4. **Mechanical Sieve Shaker**: Good Condition.

5. **Riffle**: A box with a few parallel vertical divisions.

The test procedure was according to AS1141.11 – 1996. The procedures were as below:

1. The required sieves were placed in the order of decreasing size from top to bottom. Placed the collected aggregate in the top sieve.

2. The sieves were shacked up and down mechanically with a rate of 100 strokes per minutes.

3. Force through the aggregate more than 19mm size by hand. Sieve was ended when no more than 1 percent of aggregate by weight passed from the sieve layer.

4. The mass of the aggregate in each sieve was determined by weighting.

Figure 3.3: Sieve Machine for Course Aggregate.

Figure 3.4: Sieve Machine for Fine Aggregate.

3.2.2 Result and Analysis

Table 3.4: Percentage sieve size passing for all aggregate.

Sieve size (mm)	Percentage passing (%)					
	Natural 20mm	Natural 10mm	Natural 7mm	Recycled 14mm	Recycled 5mm	Sand
19.00mm	100.00	100.00	-	100.00	-	-
13.20mm	44.48	100.00	-	95.98	100.00	-
9.50mm	8.09	90.51	100.00	29.41	98.51	-
4.75mm	0.53	1.21	18.06	0.23	2.86	-
2.36mm	0.37	0.34	2.09	0.14	0.21	98.86
1.18mm	0.35	0.31	0.75	-	0.19	96.93
600μm	-	-	-	-	-	90.45
300μm	-	-	-	-	-	58.54
150μm	-	-	-	-	-	19.28
75μm	-	-	-	-	-	4.72
Pan	0.13	0.21	0.57	0.00	0.00	2.80

The result of sieve analysis is an important factor when determine the amount of different aggregate used in a concrete mix. From the obtained result, most of the natural aggregate and recycled aggregate passed through 19mm sieve size, but less than 1% of aggregate passed through 1.18mm sieve size. Almost all the recycled aggregate passed through 13.20mm sieve size, but only 80% of natural aggregate passed through 13.20mm sieve size. Around 60% of natural aggregate and recycled aggregate passed through 9.50mm sieve size. Most of the sand particle passed through 600μm sieve size.

3.3 Mix Design

Before having any concrete mixing, the selection of mix materials and their required materials proportion must done through a process called mix design. There are lots of methods for determine concrete mix design. According to Sullivan (2003), the method called British Method was widely used in Australia. In this project, altogether eight batches of mixtures were determined in this project.

The initial mix batch will be 100% natural aggregate mix batch. Second mix batch was 80% natural aggregate and 20% recycled aggregate. There was increased of every 20% of recycled aggregate added into every series of mix batch. To fully compare the different types of full recycled aggregate concrete, there were three mix batches that contained of 100% recycled aggregate. Two batches of 100% recycled aggregate were used different water cement ratio and the remaining one batch was mixed with blended cement.

Usage of fly ash cement in construction had gained increasing acceptance by structural engineers. According to Kelvin (2003), high volume of fly ash concrete mixes may be used effectively for applications where the surface exposure is minimal. Kelvin (2003) stated that the difference between fly ash and Portland cement is the fly ash particles are spherical in shape, which allowed them to flow and blend freely in mixture. This capability is one of the properties that make fly ash as a desirable admixture for concrete. He also stated that the spherical shape of fly ash creates a “ball bearing”, which improved the workability of concrete mixes without assign more water. The spherical shape of fly ash also improves the consolidation of concrete. Other benefits that can obtain through usage of fly ash in concrete are resistance to corrosion of concrete reinforcement, attack from Alkali – silica reaction, sulfate attack, and salt attack.

Table 3.5: Percentage of aggregate used in all 8 batches of mixes.

	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6 to 8
Natural aggregate (%)	100	80	60	40	20	0
Recycled aggregate (%)	0	20	40	60	80	100

Table 3.6: Initial data for mix design.

Target strength (MPa)	50
Water/cement ratio	0.45
Aggregate / cement ratio	4.1
Weight of cement per bag (kg)	40

Table 3.7: Proportion and weight of each mix materials.

Batch	**1** (kg)	**2** (kg)	**3** (kg)	**4** (kg)	**5** (kg)	**6** (kg)	**7** (kg)	**8** (kg)
cement	16.48	16.23	15.97	15.63	15.40	15.19	19.73	15.19
water	6.93	7.29	7.52	7.71	7.91	8.11	4.95	8.11
20mm	21.01	16.58	12.40	7.66	3.78	0.00	0.00	0.00
10mm	10.78	8.63	5.88	3.83	1.89	0.00	0.00	0.00
7mm	12.76	9.93	7.16	5.10	2.51	0.00	0.00	0.00
14mm	0.00	5.10	10.03	14.72	19.35	23.84	31.51	23.84
5mm	0.00	3.17	6.87	10.39	13.25	16.04	21.39	16.04
sand	21.15	20.83	20.49	20.05	19.77	19.49	31.92	19.49
total	89.11	87.75	86.32	85.10	83.86	82.67	109.50	82.67

3.4 Mixing of Concrete

The performance of the recycled aggregate concrete was influenced by the mixing. This means that a proper and good practice of mixing can lead a better performance and quality of the recycled aggregate concrete. The quality of the concrete also can influence by the homogeneity of the mix material during the mixing and after the placement of fresh concrete. A proper mix of concrete is encouraged to the strength of concrete and better bonding of cement with the aggregate.

Once the concrete mix design was calculated, the mixing of the concrete can be carried out. The mixing of recycled aggregate concrete was carried out with an electrical 60 litres pan mixer, which was conducted in the concrete laboratory of University of Southern Queensland. Before the concrete mixing begins, all of the mix materials were weighted and prepared according to the mix design.

3.4.1 Apparatus and Test Procedure of Mixing

The apparatus and equipments used for mixing were as below:

1. **Mixer: A** pan mixer with capacity of 60 litres mixing.

2. **Buckets**: Suitable size of buckets for containing the materials before mixing.

3. **Wheel Barrier**: A suitable size of wheel barrier to contain the fresh concrete for workability tests and also place the fresh concrete into the moulds.

The test procedure for the process of mixing was as below:

1. All of the material was weighted and prepared according to the mix design.

2. Before the mixing begins, the surface of the mixer was damped with a wet cloth.

3. All of the aggregate were added into the mixer till the aggregate uniformly distributed throughout the mixer.

4. The cement was poured into the mixer after the aggregate were added.

5. The water was added into the mixer slowly while the mixing of the aggregate and cement was going on.

6. The concrete was mixed approximately 3 minutes after the water was added.

7. The mixer was off after 3 minutes of mixing.

8. The handle of the mixer was opened to allow the concrete to fill into the wheel barrier for workability test and casting of concrete.

Figure 3.5: Horizontal Pan Mixer

3.5 Placing, Compaction and Casting of Concrete Specimens

Before the placing of concrete, the concrete mould must be oiled for the ease of concrete specimens stripping. The oil used is a mixture of diesel and kerosene. Special care was taken during the oiling of the moulds, so that there no concrete stains and left on the moulds. Once the workability test of recycled aggregate concrete was done, the fresh concrete must placed into the concrete moulds for hardened properties tests. Every batch of recycled aggregate concrete required 15 small cylinders and 2 large cylinders. The dimensions of small cylinder were 100mm diameter by 200mm height, while the large cylinder was 150mm diameter by 300mm height.

During the placing of fresh concrete into the moulds, vibrations were done using an immersion vibration. The vibration of concrete allows full compaction of the fresh concrete to release any entrained air voids contained in the fresh concrete. If the concrete specimens were not compact in a proper manner, the maximum strength of the concrete cannot be achieved. The vibration was done every sufficient one third layer of the fresh concrete was poured into the moulds. It is found that the placing and compacting of concrete is getting difficult when the percentage of recycled aggregate increased. This shows that the workability of recycled aggregate used in the concrete is very poor.

The levelling of concrete was done on the surface of the concrete. Levelling is the initial operation carried out after the concrete has been placed and compacted. After the levelling of the fresh concrete specimen was done, the concrete in the mould was left overnight to allow the fresh concrete to set.

Figure 3.6: Cylinder Moulds for the Concrete Specimens.

Figure 3.7: Vibrator for Fresh Concrete Compaction.

3.6 Stripping and Curing of Concrete Specimens

After leaving the fresh concrete in the moulds to set overnight, the concrete specimens in the moulds were stripping. The identification of concrete specimens was done and the moulds were cleaned and oiled for the next batch of concrete mix. All concrete specimens were placed into the curing room with a controlled temperature of 25ºc in further for 28 days for the hardened properties test of recycled aggregate concrete.

Curing is an important process to prevent the concrete specimens from losing of moisture while it is gaining its required strength. Lack of curing will tends to lead the concrete specimen to perform less well in its strength required. Inadequate curing will cause the unexpected cracks appear on the concrete specimens. After 28 days of curing, the concrete specimens were removed from the curing room to conduct hardened properties test of recycled aggregate concrete. However, the small cylinders were taken out at the required day for the compressive test.

Figure 3.8: Curing Room for Concrete Specimens.

3.7 Summary

It shows that the mix design depends on the variables of aggregate/cement ratio, water absorption, particles density and proportioning of the aggregates. It seems that volume of aggregate for each mix batches were different.

Once the fresh concrete was mixed, the workability test of the fresh concrete will be conduct. Moreover, after required days of the concrete specimens were cured, the compression test was conducted on day 1, 3, 7, 14 and 28. On day 28, the indirect tensile test and modulus of elasticity test will be conducted. All the test procedures and methods on workability and hardened properties were discussed in chapter 4.

Chapter 4

Experimental Methodology

4.1 Introduction

This chapter discussed on the testing procedure for the workability test and hardened concrete specimens test. Workability test included slump test and compacting factor test. Hardened concrete specimens tests included compression test, indirect tensile test and modulus of elasticity.

4.2 Workability Tests of Fresh Concrete

Sabaa and Ravindrarajah (1999) had mentioned that workability is a very important property of concrete which will affect the rate of placement and the degree of compaction of concrete.

Cement Association of Canada (2003) stated that the workability is the ease of placing, combining and finishing freshly concrete mixed and the degree to which it resists segregation.

According to Cement Manufacturer's Association India (n.d), a good concrete must has workability in the fresh state and also develop sufficient strength. It also mentioned that there are four factors that can affect the workability. They are as below:

1. ***Consistency***: The degree of consistency is depended on the nature of works and type of compaction.

2. ***Water/cement Ratio or Water Control of a concrete***: Water/cement ratio is the ratio of water in a mix to the weight of cement. The quality of water that required for a mix is depended on the mix proportions, types and grading of aggregate.

3. ***Grading of Aggregate***: The smooth and rounded aggregate will produce a more workable concrete than the sharp angular aggregate.

4. ***Cement Content***: The greater workability can be obtained with the higher cement content.

This chapter will describe two types of test produce and workability tests. The tests are slump test and compacting test. Results and analysis of the results are also discussed in this chapter.

4.2.1 Slump Test

Slump test is used to determine the workability of fresh concrete. The test is simple and cheap. It is suitable to use in the laboratory and also at site. Although the test is simple, but the testing has to be done carefully due to a huge slump may obtain if there is any disturbance in the process.

Logic Sphere (n.d.) mentioned that the slump test will give a reasonable indication of how easily a mix can be places although it does not directly measure the work needed to compact the concrete. It also mentioned that a slump less than 25mm will indicate a very stiff concrete and a slump that more than 125mm will indicates a very runny concrete.

Australia Standard (2002) stated that slump test will not indicate well for the concrete with very high workability and also very low workability. This is because a very high workability concrete will lose the shape by flowing and collapse, where a very low workability concrete will not collapse.

4.2.1.1 Apparatus and Test Procedure of Slump Test

The following apparatus and equipments used were complied with the AS 1012.3.1 – 1998.

1. ***Mould:*** A hollow frustum of a cone that made from galvanized steed sheet. The thickness is between 1.5mm to 2mm. The mould has a foot piece, and handles on outer surface, and smooth internal surface. The bottom diameter of the mould is 200mm, the top diameter of the mould is 100mm and the vertical diameter of the mould is 300mm.

2. ***Rod:*** A metal rod of 16mm diameter, 600mm long and having a 25mm height of spherical shape at one end with a radius of 5mm.

3. ***Base plate:*** A 3mm thickness of a smooth, rigid and non absorbent material base metal plate.

4. ***Scoop:*** A suitable size to carry the aggregate of concrete.

5. ***Ruler:*** A suitable steel ruler to measure the height of slump.

Figure 4.1: The Apparatus for Slump Test

The test procedure was according to the AS 1012.3.1 – 1998. The procedures were as below:

1. Before the test, the internal surface of the mould was cleaned and moistened with a damp cloth.

2. The mould was placed on a smooth and horizontal surface that free from vibration or shock. While the mould was being filled, it was hold firmly by standing on the foot pieces.

3. The mould was filled in three layers. Each layer was around one – third of the height of the mould. Each layer was being rod with 25 strokes of rounded end of the rod. Each stroke has rod in a uniform manner that over the cross section of the mould.

4. The surface concrete was rolled off after the top layer has been rod. Then, remove the mould immediately by raising it slowly and carefully in the vertical direction.

5. Measured the height of slump immediately. It was determined between the height of the mould and the average height of the top surface of the concrete.

Figure 4.2: Typical Slump Test

4.2.2 Compacting Factor Test

Compacting factor test also used to determine the workability of fresh concrete. It is not used on site testing because the apparatus is very heavy. According to Streetworks Info (n.d.), the compacting factor test gives a more accurate workability of fresh concrete than slump test. It mentioned that the compacting factor test also known as the "drop test", which measures the weight of fully compacted concrete and compare it with the weight of partially compacted concrete.

All the procedures for the compacting factor test is carried out by according to the AS 1012.3.2 – 1998.

Figure 4.3: The Apparatus for Compacting Factor Test

4.2.2.1 Apparatus and Test Procedure of Compacting Factor Test

The following apparatus and equipments used were complied with the AS 1012.3.2 – 1998.

1. ***Compacting Factor Apparatus***: It consists of two conical hoppers mounted above a cylinder. The hoppers and cylinder are made from the rigid materials that not readily attack by cement paste. The rim of the cylinder is perpendicular from the plane surface to its axis. The frame that the hoppers and cylinder mounted shall be rigid construction and locate in the right construction and locate in the right position. The cylinder has to be easy to take off from the frame.

2. ***Trowels***: There are two trowels are required.

3. ***Scoop***: A suitable size of scoop to take the increments of concrete.

4. ***Rod***: A metal rod of 16mm in diameter, 600mm long and having a 25mm height of spherical shape at one end with a radius of 5mm.

5. ***Balance***: A balance that capable of weighing to an accuracy of 0.1percent in the operation range.

6. ***Level***: A suitable level is required.

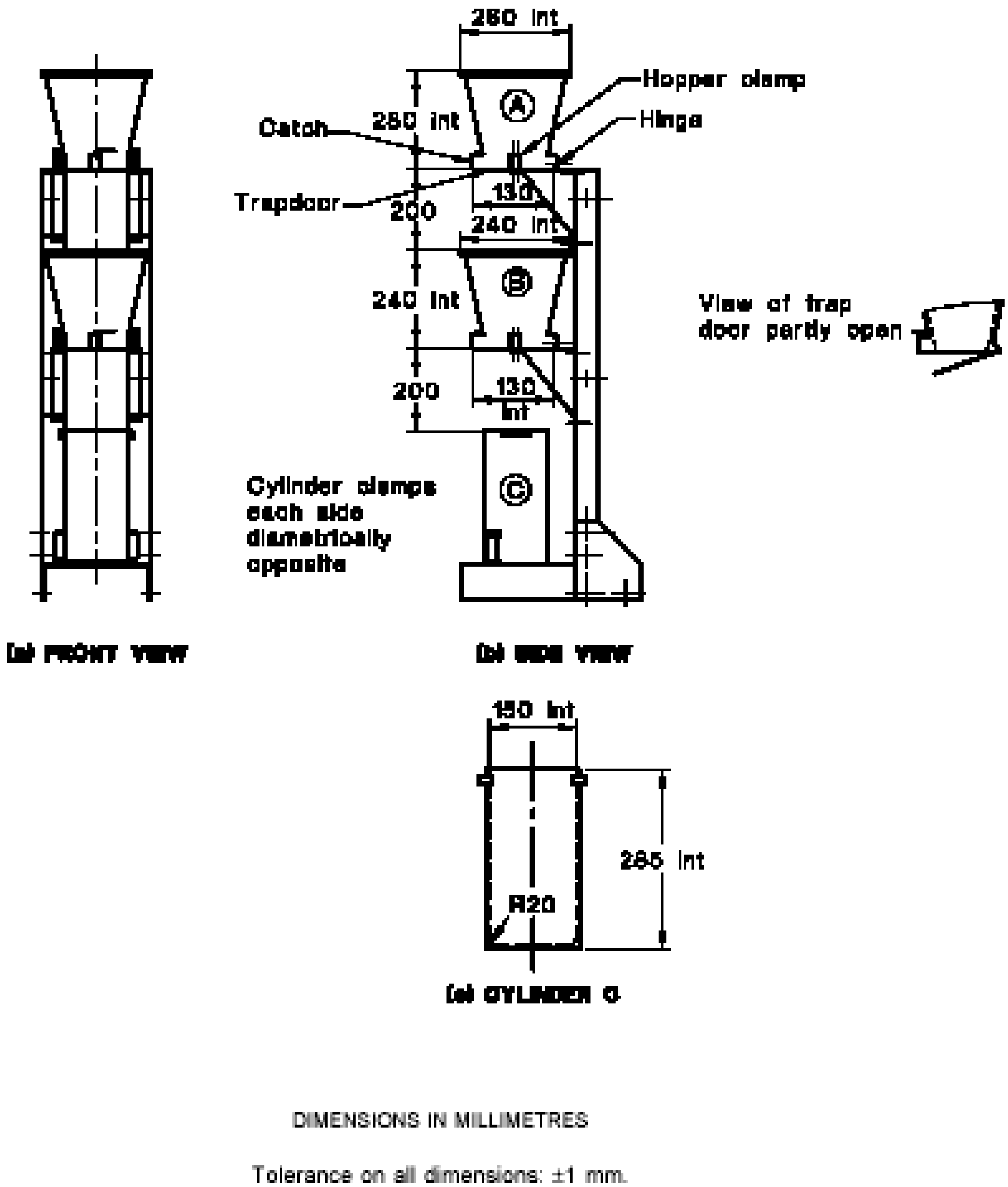

Figure 4.4: Standard Compacting Factor Apparatus

(Source: AS1012.3.2, 1998)

The test procedure was according to the AS 1012.3.2 – 1998. The procedures were as below:

1. Before the test, the internal surface of the mould was cleaned and moistened with a damp cloth.

2. The apparatus was placed on a level rigid surface that free from vibration or shock.

3. The concrete was placed in the upper hopper until the hopper is filled. Opened the trapdoor and let the concrete fell into the lower hopper.

4. Opened the trapdoor of the lower hopper and let the concrete fell into the cylinder.

5. Cut off the concrete that excess the level of the cylinder by holding a towel in each hand.

6. The mass (M_1) of concrete in the cylinder was determined (Mass of the partially compacted concrete) and recorded.

7. The cylinder was empty and filled with the concrete again in the layers around 50mm deep. Each layer was rod with the metal rod, until compaction was achieved.

8. The mass (M_2) of concrete in the cylinder was determined again (Mass of fully compacted concrete) and recorded.

The compacting factor was determined from the following equation:

$$\text{Compacting Factor} = \frac{\text{Mass of partially compacted concrete } (M_1)}{\text{Mass of fully compacted concrete } (M_2)}$$

4.3 Testing on Hardened Concrete Specimens

Concrete is a combination of Portland cement, water and aggregate that consists of rocks and sand. Normally, concrete is strong in compression but weak in tension.

There are many ways that we can used to indicate the strength of concrete, according to University of Florida (n.d.), the tests used to indicate the strength of concrete can be categorized as destructive and non – destructive tests.

The testing for the strength if concrete is very important in the civil works. University of Florida (n.d.) also mentioned that the engineers can compare the value of the testing to the designed value used for the building structure. This is to make sure that the structure was built well.

This chapter consists of three types of hardened concrete testing. They are compression test, indirect tensile test and modulus of elasticity. All the procedure used was according to the Australia Standard Code.

4.3.1 Compression Test

According to Cement Association of Canada (2003), compressive strength of concrete can be defined as the measured maximum resistance of a concrete to axial loading. Compression test is the most common test used to test the hardened concrete specimens because the testing is easy to make. The strength of the concrete specimens with different percentage of recycled aggregate replacement can be indicating through the compression test.

The specimens used in the compression test were 100mm diameter and 200mm height. There are three specimens were used in the compression testing in every batches. Differences of the strength among the different percentage of recycled aggregate used in the age of 1, 3, 7, 14, and 28 days also indicated through the compression test. The compression test was carried out in the engineering laboratory of University of Southern Queensland. The compression testing procedures was according to the Australia Standard Code.

4.3.1.1 Apparatus and Test Procedure of Compression Test

The apparatus and equipments used in the compression test were according to AS 1012.9 – 1999.

1. **Testing Machine**: ‘Avery’ testing machine.

2. **Rubber Cap**: A suitable diameter of rubber cap.

3. **Ruler**: 400mm long ruler to measure the height of specimen.

4. **Balance**: To measure the weight of the concrete specimens.

5. **Vernier Caliper**: To measure the diameter of the concrete specimens.

The test procedure was according to the AS 1012.9 – 1999. The procedures were as below:

1. The testing for the specimens should be carried out as soon as possible after took out from the curing room. The specimens need to get the measurements before the testing.

2. The diameter and height of the specimens were measured and recorded. The weight of each specimen was measured and recorded too.

3. The platens of the testing machine were cleaned with a clean rag.

4. Cleaned the uncapped surface of the specimen and place the specimen in the testing machine. The axis of the specimen was aligned with the centre of the thrust of the spherically seated platen.

5. Carefully placed the rubber cap on the specimen.

6. The platen was lowered to the rubber cap until the uniform bearing was obtained.

7. The force was applied and increased continuously at a rate equivalent to 20MPa compressive stress per minute until the specimen failed.

8. Recorded the maximum force from the testing machine.

Figure 4.5: Setup of Compression Test

4.3.2 Indirect Tensile Test

Normally, concrete is very strong in compression but weak in tension. Indirect tensile test is used to indicate the brittle nature of the concrete specimens that contained of different percentage of recycled aggregate replacement. Indirect tensile test also called as the Brazil of splitting test. According to the Composition and Properties of Concrete (n.d.), the indirect tensile test will give more uniform results than other tension tests. It also mentioned that the result obtained by the indirect tensile test is closer to the true tensile strength of concrete than the modulus of rupture.

The indirect tensile test was just carried out after 28days of casting. It is because once the concrete specimens reach day 28, the increased rate of concrete stress was uniform and there is not much stress increased after 28days.

The testing specimen was 150mm diameter and 300mm length. Two specimens were used in the testing for every batch. The indirect tensile test was carried out in the

University of Southern Queensland engineering laboratory. All the testing procedures were according to the Australia Standard Code.

4.3.2.1 Apparatus and Test Procedure of Indirect Tensile Test

The following apparatus and equipments used in the indirect tensile test were according to the AS 1012.10 – 1999.

1. **Testing Machine**: ‘Avery’ testing machine.

2. **Testing Jig**: An appropriate size of steel jig.

3. **Supplementary Bearing Bar or Plate**: Width of 50mm and thickness of 20mm.

4. **Bearing Strips**: Two grade hardboard widths of 5mm thick, 25mm wide and 300mm long.

5. **Ruler**: 400mm long, to measure the height of the concrete specimens.

6. **Vernier Caliper**: To measure the diameter of the concrete specimens.

The test procedure is according to the AS 1012.10 – 1999. The procedures were as below:

1. Measured the diameter and length of the specimen. Recorded the measurements.

2. Placed the specimen on the testing jig. Bearing strips were aligned on the top and bottom of the specimen and placed the bearing plate outside the bearing strips.

3. Applied a small initial force and the side constrain was removed.
4. Applied the force without shock and increased continuously at a constant rate of 15MPa.

5. Recorded the maximum force from the testing machine when the specimen failed.

Figure 4.6: Setup of Indirect Tensile Test

4.3.3 Modulus of Elasticity

Modulus of elasticity of concrete is a very important property to determine the deflection of the structural elements. According to Cement Association of Canada (2003), deflection of concrete beams and slabs is a common building movement. It also mentioned that the deflection is the result of the flexural strains that develop under dead and live loads and this may occur cracking in the tensile zone.

The modulus of elasticity testing is used to determine the deflection of the concrete specimens that having different percentage of recycled aggregate replacement. The testing is just carried out after 28 days of casting. The resting specimen was 150mm diameter and 300mm height. The modulus of elasticity test was carried out in the University of Southern Queensland engineering laboratory.

4.3.3.1 Apparatus and Test Procedure of Modulus of Elasticity Test

The apparatus and equipments used were as below:

1. **Testing Machine**: 'Avery' testing machine.

2. **Strain Measuring Equipment**.

The test procedure was according to the AS 1012.17 – 1999. The procedures were as below:

1. All of the measurement on the diameter and height of the concrete specimens was measured using Vernier Caliper and recorded in the record book.

2. Using the data from compressive test, the maximum load was estimated by multiplying the cross sectional area of the modulus of elasticity's concrete specimen to the average compressive strength from compressive strength test of particular batch.

3. Once the maximum load for each specimen was determined, the 60% of estimated ultimate load was obtained for the requirement for modulus of elasticity test.

4. The load meter of 'Avery' test machine was marked at every 25kN of load interval with a red marker pen until the 60% of estimated ultimate load.

5. The strain-measuring equipment was set at the concrete specimen.

6. Once the strain-measuring equipment was placed, the screws on top and bottom of the equipment were loosened. Consequently, the hollow bars in between the top and bottom were taken away.

7. The concrete specimen with the strain-measuring equipment was positioned at the ‘Avery’ test machine with care.

8. Rubber capping was placed on the rough surface of the concrete specimen.

9. The loading platen of the test machine was brought to the top of the specimen. A seating load was applying with not exceeding 100N to the top of the rubber capping.

10. The concrete specimen was checked and placed firmly on the test machine and in between the top and bottom steel platens. Once, this check was done, the strain gauges was set to zero to eliminate zero detects.

11. Applied the force without shock and increased continuously at a constant rate of 15MPa.

12. Recorded the force that applied at every 25kN. Stop the testing when the force had reached the estimated ultimate load.

Figure 4.7: Setup of Modulus of Elasticity

4.4 Summary

It shows that all the test procedures and methods are according to Australia Standard. Due to the records of the test results, it was found that test machine and human error may affect the accuracy of the results. To overcome these problems, all the test specimens were tested to obtain its average values. The results of each testing and each discussion will be discussed in chapter 5.

Chapter 5

Tests Results and Analysis

5.1 Introduction

Series of test was carried out on the concrete cylinder to obtain the strength characteristics of recycled aggregate for potential application in high strength structural concrete. This chapter discuss on the results that obtained from the testing. The results are such as slump test, compacting factor test, compression test, indirect tensile test and modulus of elasticity.

5.2 Slump Test Result and Analysis

The slump test indicates a decreasing trend of workability when the percentage of recycled aggregate increased. Table 5.1 below shows the average slump recorded during the test. Figure 5.1 below shows a graphical representation of slump height.

Table 5.1: The slump result for each batch of mix concrete

Percentage of Recycled Aggregate (%)	Slump (mm)
0% recycled aggregate	90
20% recycled aggregate	85
40% recycled aggregate	85
60% recycled aggregate	82
80% recycled aggregate	81
100% recycled aggregate (with 0.43 water/cement ratio)	78
100% recycled aggregate (with 0.36 water/cement ratio)	64
100% recycled aggregate (with fly ash cement)	80

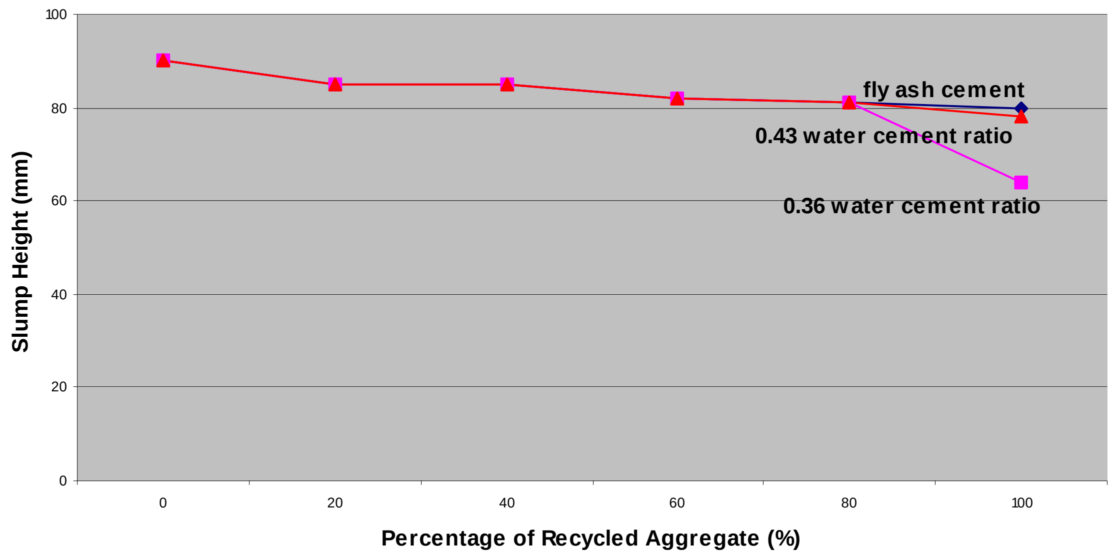

Figure 5.1: Graph showing the result of Slump Test

According to the result, the highest slump obtained was 90mm and the lowest slump was 64mm. The average slump for each batch of mix was 82mm. Therefore, target slump had been achieved, where the range is from 50mm to 120mm.

The workability was good and can be satisfactorily handle for 0% recycled aggregate to 80% recycled aggregate. The slump from 0% recycled aggregate to 80% recycled aggregate were considered moderate due to the drop in the range of 5mm to 9mm.

The average slumps that obtained for 100% recycled aggregate (with 0.43 water cement ratio) and 100% recycled aggregate (with fly ash cement) was 79mm. There was no problem for the placement and compaction of fresh concrete in these two batches. The only problem that obtained was the batch with 100% recycled aggregate (with 0.36 water cement ratio). The workability was very low due to the slump was just 64mm. The reason was because of the high absorption capacity of recycled aggregate.

From the result obtained, it shows that the workability was getting lower when more recycled aggregate were used.

5.3 Compacting Factor Test Result and Analysis

The compacting factor indicates a moderate decreasing trend of workability when the percentage of recycled aggregate increased. Table 5.2 below shows the compacting factor ratio recorded during the test. Figure 5.2 below shows a graphical representation of compacting factor ratio.

Table 5.2: The compacting factor ratio for each of mix concrete

Percentage of Recycled Aggregate (%)	Partially Compacted	Fully Compacted	Compacting Factor Ratio
0% recycled aggregate	25.07	25.08	1.000
20% recycled aggregate	24.40	24.43	0.999
40% recycled aggregate	25.62	25.70	0.997
60% recycled aggregate	25.19	25.31	0.995
80% recycled aggregate	24.64	24.96	0.987
100% recycled aggregate (with 0.43 water cement ratio)	23.76	24.53	0.969
100% recycled aggregate (with 0.36 water cement ratio)	21.34	23.28	0.917
100% recycled aggregate (with fly ash cement)	25.01	25.57	0.978

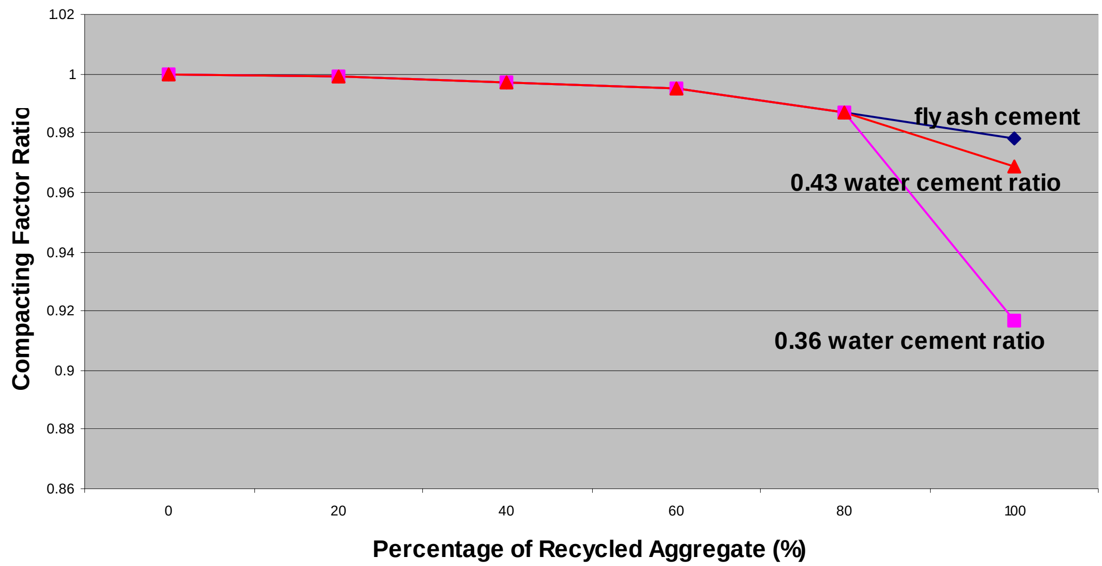

Figure 5.2: Graph showing the result of Compacting Factor Ratio

Figure 5.2 shown that the compacting factor ratio is decreasing as the percentage of recycled aggregate increased. The result is very similar to the result of slump test. The highest compacting factor ratio is 1.000 and the lowest is 0.917.

The average of compacting factor ratio for 0% recycled aggregate to 80% recycled aggregate is 0.996. The average of compacting factor ratio for 100% recycled aggregate (with 0.43 water cement ratio) and 100% recycled aggregate (with fly ash cement) is 0.973. There is no problem in handle and compact the fresh concrete in these batches.

The lowest workability is the batch with 100% recycled aggregate (with 0.36 water cement ratio), which is 0.917. This is the batch that problem occurred during the handling and compaction of fresh concrete. The reason is due to the high absorption capacity of recycled aggregate.

From the result obtained, we can say that the workability is getting lower due to the increasing of recycled aggregate used.

5.4 Compression Test Result and Analysis

The compression test indicates that an increasing trend of compressive strength in the early age of the concrete specimens. However, it shows that the strength of recycled aggregate specimens is lower than natural aggregate specimens. Table 5.3 below shows that the compressive strength with age recorded during the test. Figure 5.3 below shows a graphical representation of variation of variation of compressive strength decreasing of each batch was discussed.

Table 5.3: Variation of compressive strength (MPa) with age

Percentage of recycled aggregate	0%	20%	40%	60%	80%	100% (0.43 w/c ratio)	100% (0.36 w/c ratio)	100% (fly ash cement)
Day								
1	11.4	7.4	6.6	4.7	3.7	4.2	11.1	2.6
3	32.1	29.7	28.0	24.8	21.1	23.4	36.8	11.2
7	39.9	36.9	35.6	33.3	27.3	30.5	47.0	13.7
14	46.0	42.1	41.3	37.0	32.4	34.6	47.9	18.4
28	51.0	43.3	42.5	40.1	35.7	40.2	48.1	23.3

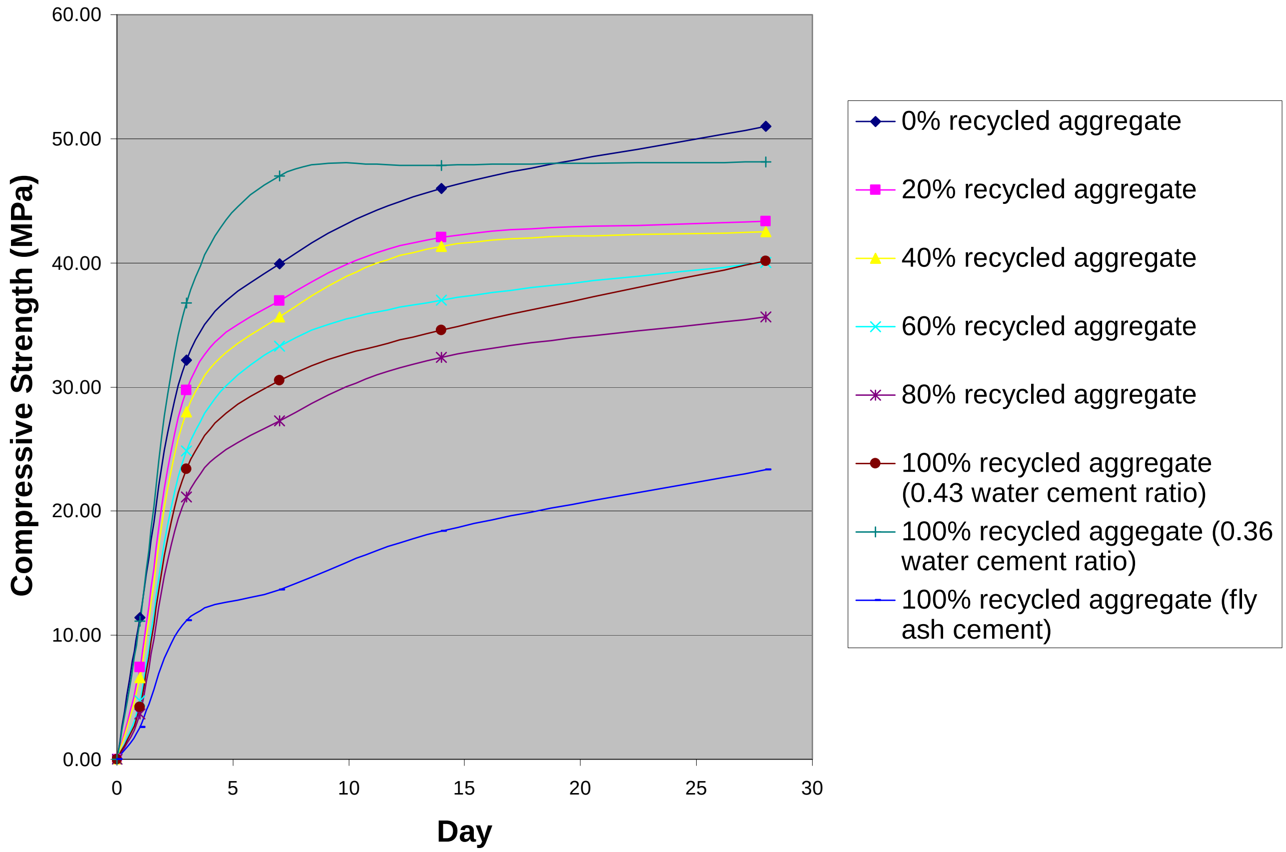

Figure 5.3: Variation of Compressive Strength with Age

The target strength for this project is 50MPa. From the obtained result, it shown that the only batch that met the target strength is the batch with 0% recycled aggregate. The compressive strength for other batches is around 40MPa; expect the concrete specimens for 100% recycled with fly ash cement. This may because of the usage of blended cement in these concrete specimens that may reduce the compressive strength while using the recycled aggregate. The compressive strength of the concrete specimens for 100% recycled aggregate with 0.43 water/cement ratio is 48.1MPa, which almost met the target strength. This shown that the 100% recycled aggregate may achieve high strength by reducing the water/cement ratio.

From figure 5.3, it shows that the strongest initial compression strength if the batch for 100% recycled aggregate with 0.36 water/cement ratio, but after day 7, the rate of increment is decreasing when compared with other batches.

The results also shows that the concrete specimens with more replacement of recycled aggregate will get the lowest strength when compared to the concrete specimens with less recycled aggregate.

Figure 5.4: Specimens after Testing

Table 5.4: Percentage of compressive strength remained and dropped

Percentage of recycled aggregate	Remained of compressive strength	Dropped of compressive strength
0%	100%	0%
20%	85%	15%
40%	83%	17%
60%	79%	21%
80%	70%	30%
100% (0.43 water cement ratio)	79%	21%
100% (0.36 water cement ratio)	95%	5%
100% (fly ash cement)	46%	54%

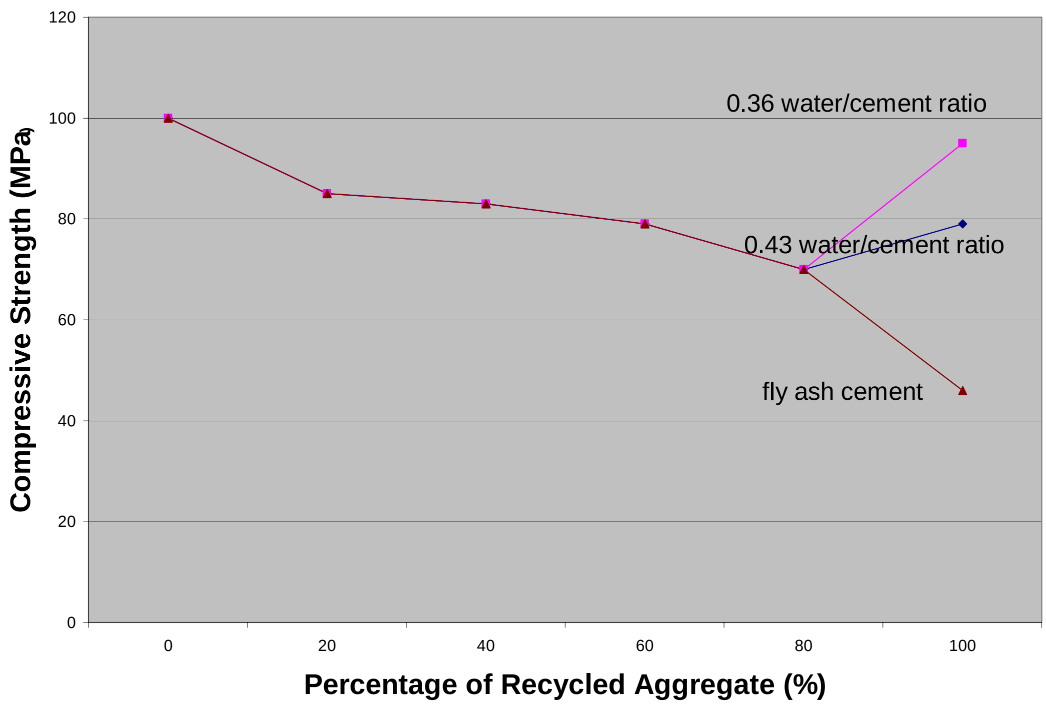

Figure 5.5: Graph shows the Percentage of Compressive Strength Remained

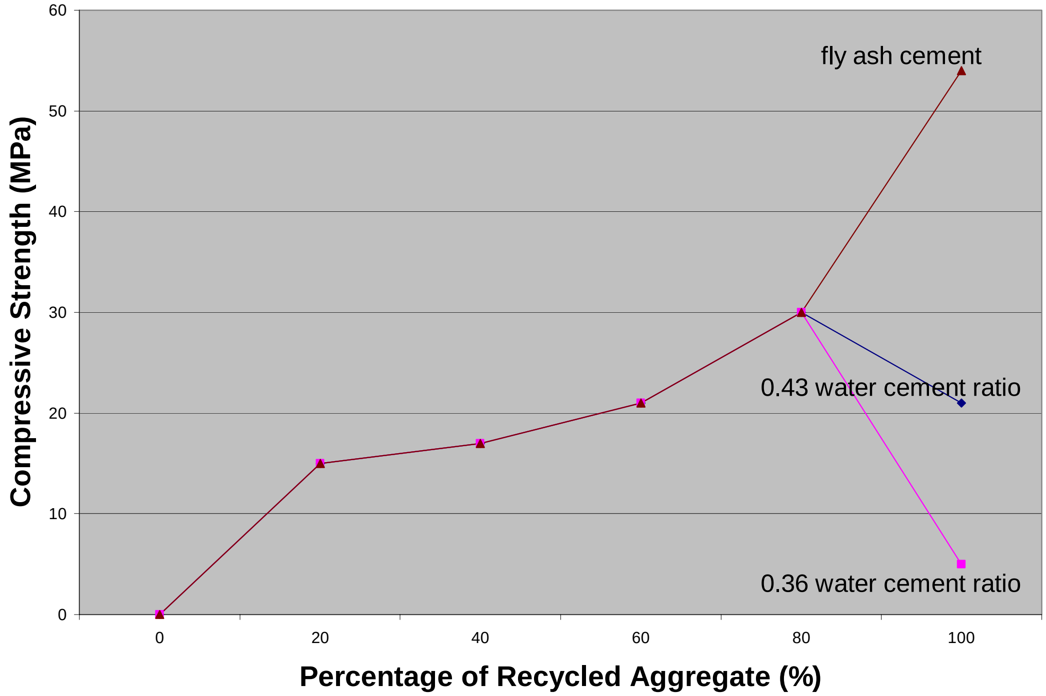

Figure 5.6: Graph shows the Percentage of Decreasing in Compressive Strength

Figure 5.6 shows the percentage of the compressive strength remained when percentage of recycled aggregate replacement increased. The compressive strength used from each batches were based on day 28 strength. The compressive strength of 0% recycled aggregate was taken as the 100% compressive strength.

From the result, the batch of 100% recycled aggregate with fly ash cement has the lowest compressive strength remained, which is only 46%. There is a drop of 54% when compared to 0% recycled aggregate. The reason is mainly because of the fly ash cement that may reduce the compressive strength of the concrete specimen.

The compressive strength for 20% recycled aggregate replacement had dropped around 15%. The concrete specimens from 0% recycled aggregate to 80% recycled aggregate replacement had the average dropped of 8%. There is a drop of 21% compressive strength for the 100% recycled aggregate (0.43 water/cement ratio), where it only drops 5% of compressive strength for 100% recycled aggregate (0.36 water/cement ratio). The main reason is because of the lower water cement ratio and also the particular size of recycled aggregate used in this batch is smaller than other concrete specimens

From the obtained result, it is possible to use 100% recycled aggregate with the less water cement ratio in the high strength structures.

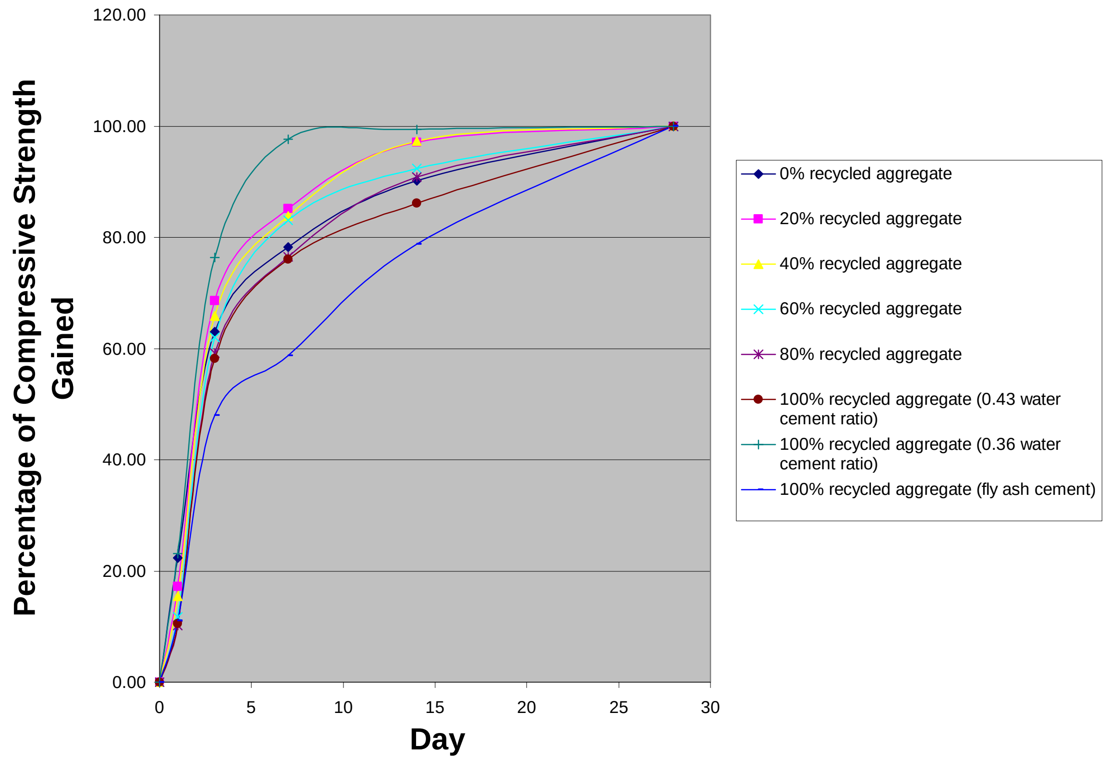

Figure 5.7: Variation of Compressive Strength Gained with Time

Figure 5.7 shows the variation of compressive strength gained with time. It indicates that how fast the structural building can support itself without any other support after the day having casting.

From the figure 5.7, the compressive strength of 100% recycled aggregate with 0.36 water/cement ratio has gained most of the strength when compared with other concrete specimens. The compressive strength of 100% recycled aggregate with fly ash cement has gained the lowest strength among all the concrete specimens. According to this figure, the compressive strength of recycled aggregate (from 20% to 60%) gained higher than the compressive strength of recycle aggregate (0%, 80% and 100% with 0.43 water cement ratio). The specimens with the 100% recycled aggregate (fly ah cement) had gained the lowest strength.

Based on the result, it shows that with the more percentage of recycled aggregate, the higher the compressive strength will gained. This means that the structural building can take off the support earlier when using the recycled aggregate.

5.5 Indirect Tensile Test Result and Analysis

The indirect tensile test indicates a decreasing trend of indirect tensile strength when the percentage of recycled aggregate increased. Table 5.5 below shows the average tensile strength recorded during the test. Figure 5.8 below shows a graphical representation of variation of tensile strength.

Table 5.5: Variation of tensile strength

Percentage of Recycled Aggregate (%)	Average Tensile Strength (MPa)
0%	3.98
20%	3.44
40%	3.32
60%	2.86
80%	2.67
100% (0.43 water/cement ratio)	3.10
100% (0.36 water/cement ratio)	3.49
100% (fly ash cement)	2.53

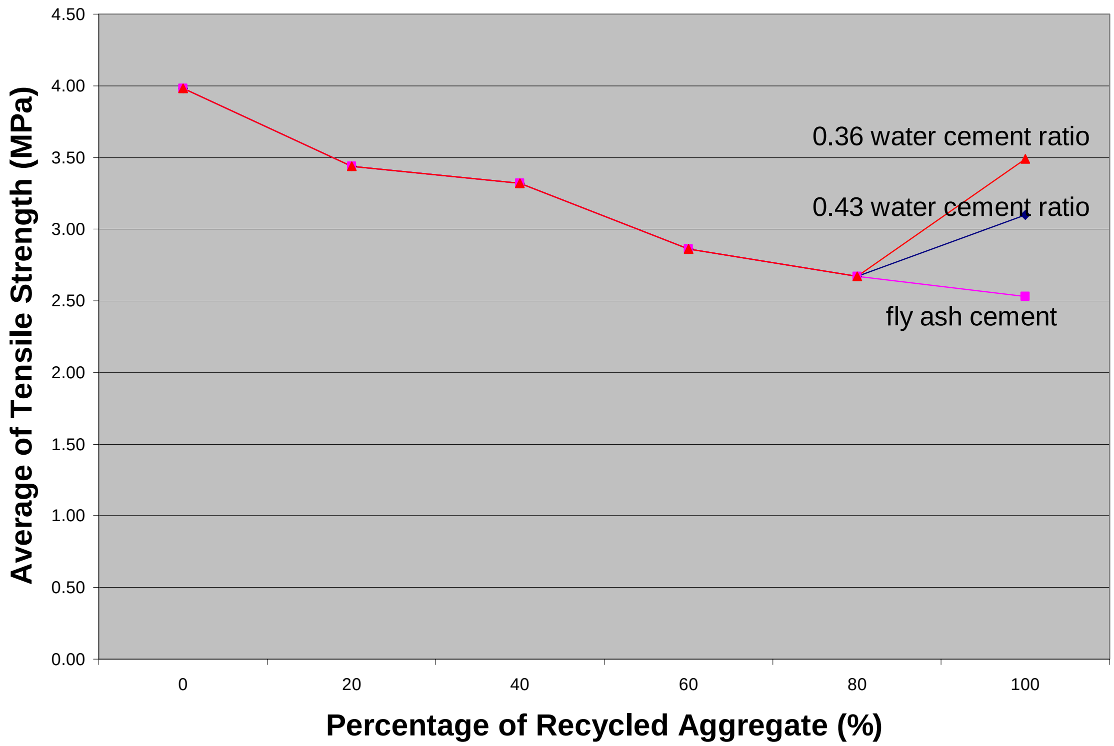

Figure 5.8: Variation of Tensile Strength

From the figure 5.8, it shows that the tensile strength is gradually decreasing for the concrete specimens that with the replacement of 0% recycled aggregate to 80% of recycled aggregate. The average tensile strength for the concrete specimens of 100% recycled aggregate (0.43 water/cement ratio) and 100% recycled aggregate (0.36 water/cement ratio) was 3.30MPa. The average tensile strength drop for the concrete specimens with the replacement of recycled aggregate (from 0% to 80%) was 0.26MPa. The concrete specimen of 100% recycled aggregate with fly ash cement had the lowest tensile strength, which was only 2.53MPa. It is around 64% drop compared to 0% recycled aggregate concrete specimen. The reason is mainly because of the fly ash cement that will reduce the tensile strength of the concrete specimen.

According to the result, it can say that the tensile strength is decreasing as the increasing in the replacement of recycled aggregate percentage. But when the water/cement ratio used in the recycled aggregate specimen is lower, the tensile stress will getting higher.

Figure 5.9: Specimens after Testing

Table 5.6: Percentage of tensile strength remained and dropped

Percentage of recycled aggregate	Remained of tensile strength	Dropped of tensile strength
0%	100%	0%
20%	86%	14%
40%	83%	17%
60%	72%	28%
80%	67%	33%
100% (0.43 water/cement ratio)	78%	22%
100% (0.36 water/cement ratio)	88%	12%
100% (fly ash cement)	64%	36%

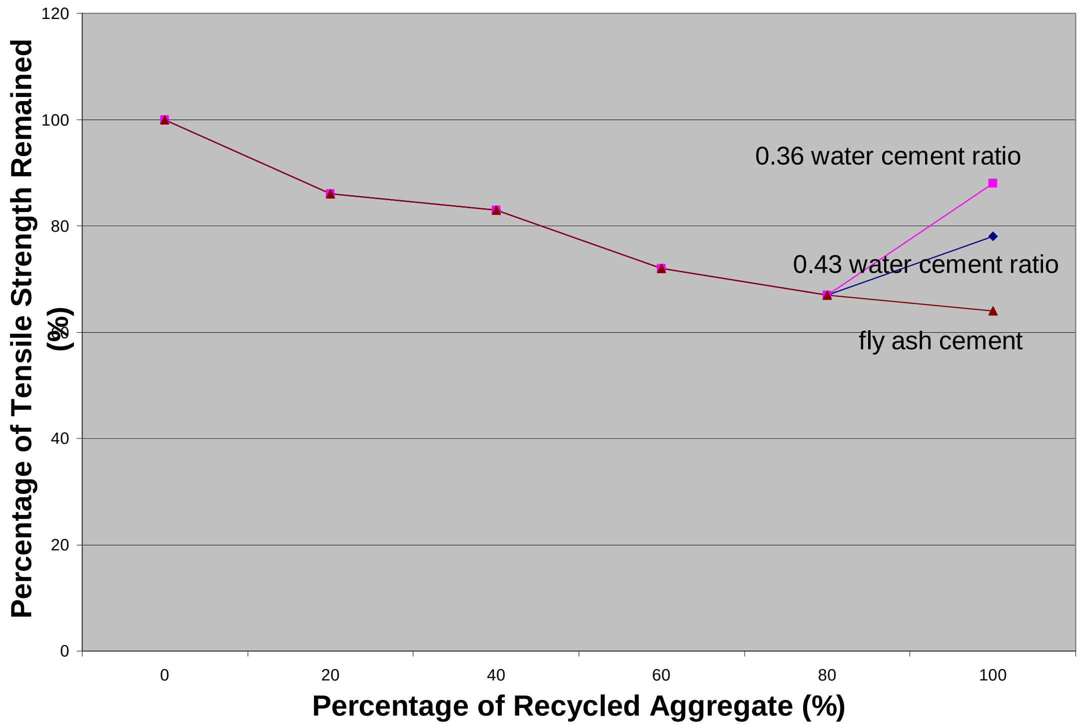

Figure 5.10: Graph shows the Percentage of Tensile Strength Remained

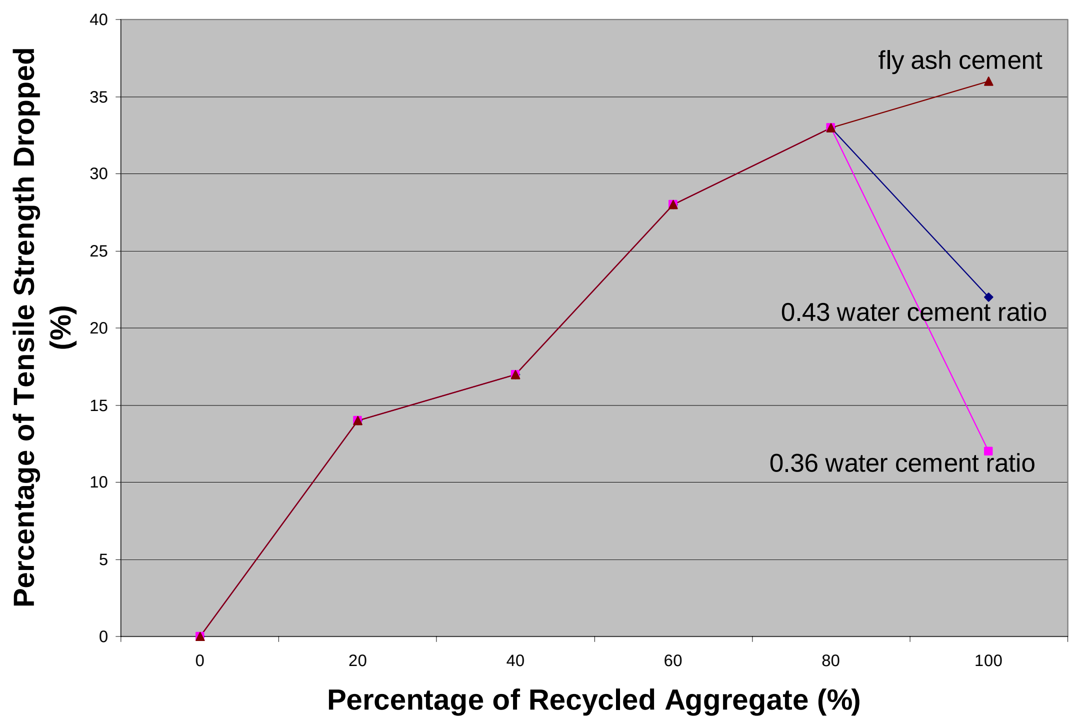

Figure 5.11: Graph shows the Percentage of Tensile Strength Dropped

Figure 5.10 shows the percentage of tensile strength remained for the concrete specimens with the different percentage of recycled aggregate replacement. The result is almost same as the result of compressive strength. The concrete specimen of 100% recycled aggregate with the fly ash cement has the lowest tensile strength remained, which is only 64%. The main reason is also cause of the fly ash cement that will reduce the strength in concrete specimen. There is a drop of 22% for the concrete specimen with 100% recycled aggregate (0.43 water/cement ratio), which is still remained 78% of tensile strength when compare to 0% recycled aggregate concrete specimen. However, the concrete specimen with the 100% recycled aggregate (0.36 water/cement ratio) has the most tensile strength remained. It just drops 12%, which is still remained 88% when compared to 0% recycled aggregate concrete specimen. The reason is because of the lower water cement ratio and also because of the particular size of recycled aggregate used is smaller than other batches of concrete specimens.

From the result, it clearly shows that with more percentage replacement of recycled aggregate used in the concrete specimen, the percentage of tensile strength remained are gradually decreasing. The tensile strength will remain higher when the water/cement ratio is getting lower.

5.6 Modulus of Elasticity Result and Analysis

The modulus of elasticity test indicates a decreasing trend of modulus of elasticity value when the percentage of recycled aggregate increased. Table 5.2 below shows the average modulus of elasticity recorded during the test. Figure 5.12 below shows a graphical representation of the variation of modulus elasticity.

Table 5.7: The results obtained from different percentage of recycled aggregate replacement.

Percentage of recycled aggregate	Modulus of elasticity (MPa)
0%	44303
20%	36641
40%	35297
60%	27906
80%	27748
100% (0.43 water cement ratio)	26422
100% (0.36 water cement ratio)	30560
100% (fly ash cement)	21342

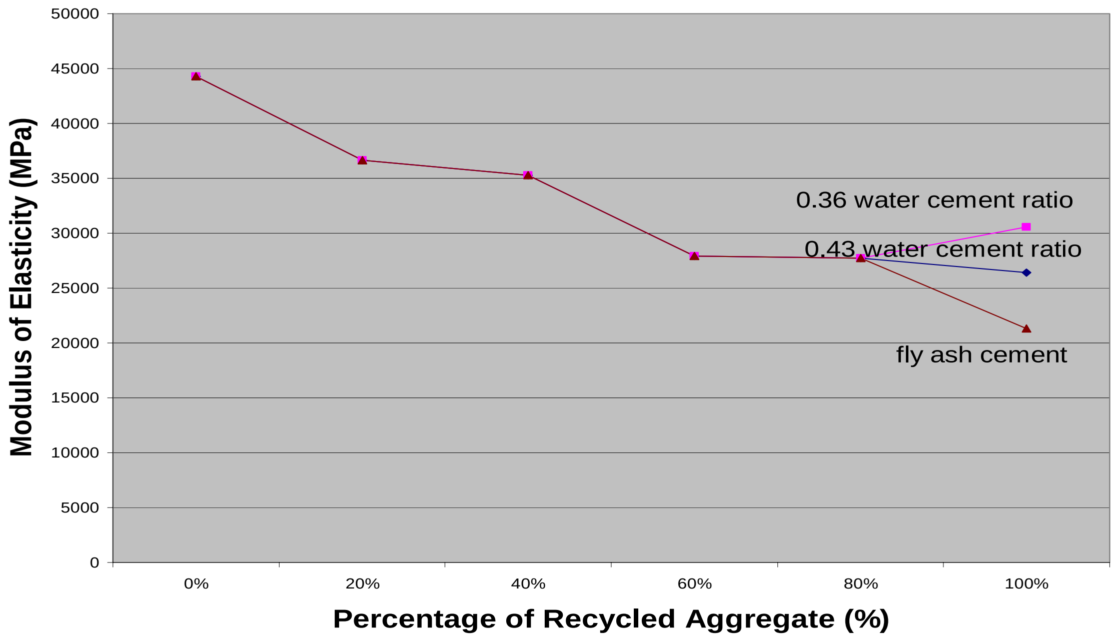

Figure 5.12: Variation of Modulus of Elasticity

Figure 5.12 indicate shows the variation of modulus of elasticity of concrete specimens with the increasing of 20% of recycled aggregate. It shows a decreasing trend occurs when the percentage of recycled aggregate increasing. Consequently, specimens made with recycled aggregate have less modulus of elasticity value than the specimens made with all natural aggregate.

From the experimental results, the modulus of elasticity of full natural aggregate specimens was 44303MPa, while the modulus of elasticity of full recycled aggregate specimens was 26422MPa. It indicates a drop of 17881MPa, which is 67% difference between the 0% and 100% recycled aggregate batches. Additionally, the difference with each 20% recycled aggregate increase is approximately 21%.

By comparing all different type of 100% recycled aggregate, the reduced water 100% recycled aggregate specimen has the highest value of modulus of elasticity, while the normal recycled aggregate (0.43% water/cement ratio) is moderate and the fly ash 100% recycled aggregate specimen was the lowest..

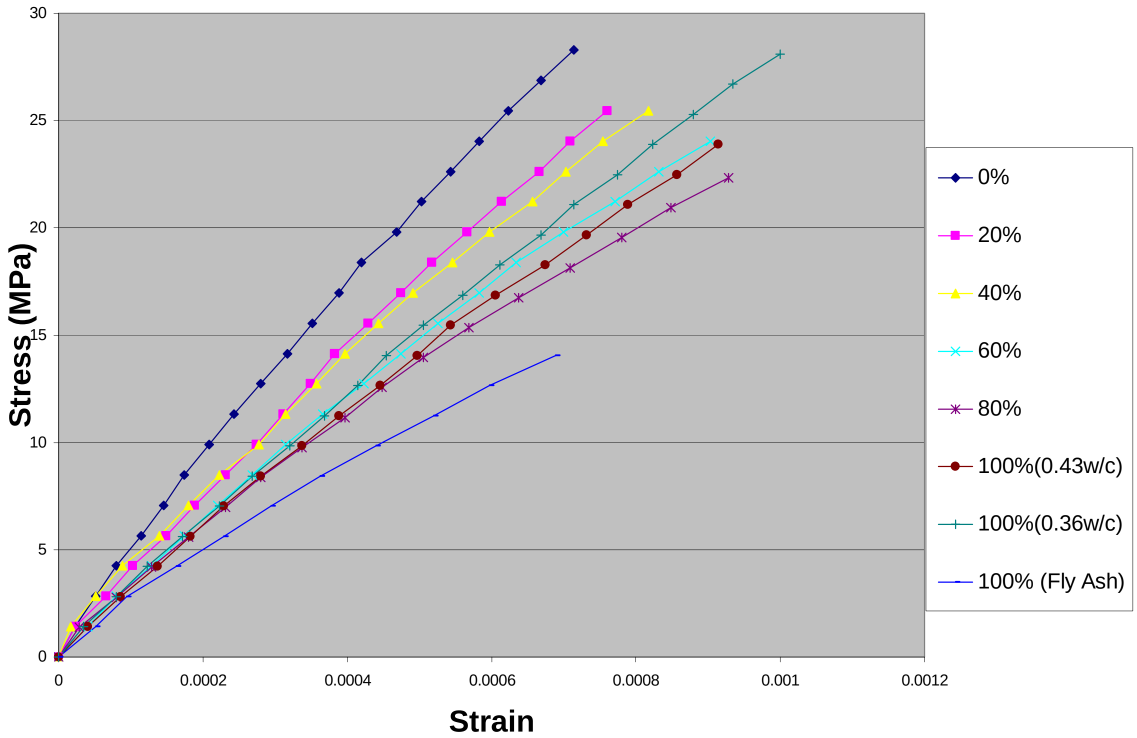

Figure 5.13: Stress and Strain Relationship

Figure 5.13 shows the stress / strain curve for all concrete specimens which taken from modulus of elasticity tests. Each specimen will represent the increasing amount of 20% of recycled aggregate.

It shows that the replacement of increase recycled aggregate percentage used in the concrete specimens, the ultimate strength of concrete decreased, while the deformation of the concrete is still remaining the same rate. This figure also shows that the slope is decreasing when the rate usage of recycled aggregate increased. However, the comparisons for all different 100% recycled aggregate are very obvious.

Comparing all recycled aggregate specimen, it shows that the 0.36% water/cement ratio recycled aggregate specimen has an increasing rate slope higher than 0.43%

water/cement ratio and fly ash recycled aggregate specimen. As this indicates these results were similar the compression strength and indirect tensile strength results.

5.7 Summary

The experimental results show the recycled aggregate will influence much in fresh and hardened properties of a concrete. As the percentage of the recycled aggregate increased, the workability and strength of the concrete will decreased. By comparing the different type of 100% recycled aggregate specimens, it was found that fly ash cement recycled aggregate concrete mix batch were not sufficient to achieve the high strength target. The reduced water (0.36 water/cement ratio) recycled aggregate concrete mix indicates a higher strength but the workability is not very satisfied.

Chapter 6

Conclusion and Recommendations

This chapter was set out to represent the conclusion of this project. Before the conclusion is list, the achievement of objectives set in beginning of the project was also discussed and achieved. Lastly, some testing, investigations and studies were also recommended after the conclusion, to further the strength characteristics of recycled aggregates for the application in high strength concrete.

6.1 Achievement of Objectives

The project achievements are as follows:

- In this project, the review and research of current usage to the use of recycled aggregate in the concrete was discussed into different sectors, such as constructions, industries, applications, recycling process, previous research and investigation.

- Total of six batches of concrete mixes required by the scope of the project. The concrete mixes consisted of every 20% increment of recycled aggregate replacement from 0% to 100%.

- The investigation and laboratory testing on recycled aggregate concrete specimens such as compression test, indirect tensile test and modulus of elasticity. However, not all the specimens had achieved to the high strength requirement.

- All the result for the tests was recorded in an appropriate manner. Moreover, result of each test was analysed in detail. All of this was discussed in chapter 5.

- With extra time permit, two extra 100% recycled aggregate concrete mixes on were cast which is water/cement ratio of 0.36 and fly ash cement. These two mixes were compared to 100% recycled aggregate concrete mix (0.43 water/cement ratio)

6.2 Conclusion

Research on the usage of waste construction materials is very important due to the materials waste is gradually increasing with the increased of population and increasing of urban development. The reasons that many investigations and analysis had been made on recycled aggregate are because recycled aggregate is easy to obtain and the cost is cheaper than virgin aggregate. Virgin aggregate need to mine but recycled aggregate can ignore this process.

This on-going research project is to determine the strength characteristics of recycled aggregate for potential application in the high concrete structural concrete. The study shows that when the water/cement ratio was decreased, the compressive strength can reach 48MPa. This is classified as high strength concrete and they can be applied in the infrastructures, which need compressive strength up to 40MPa. Furthermore, with the cheaper price of recycled aggregate compared to natural aggregate, the builders can carry out the construction task with lesser material costs.

Another result found in this research is that when reducing the water amount used in recycled aggregate mixes, tensile strength and modulus of elasticity are also improved. This will give an improvement in general strength characteristics of structural building.

Although recycled aggregate can be applied in the high strength structure, but one issue must not be neglected as recycled aggregate with reduce water content would have low workability. Whenever recycled aggregate is applied, water content in the concrete mix has to be monitored carefully due to the water absorption capacity of recycled aggregate will vary. This type of concrete can only be used under the condition that does not involve a lot of handling works.

6.3 Recommendations for Further Studies

Further testing and studies on the recycled aggregate concrete is highly recommended to indicate the strength characteristics of recycled aggregates for application in high strength concrete. Below are some of the recommendations for further studies:

- Although by decreasing the water/cement ratio, recycled aggregate can achieve high strength concrete. But the workability will be very low. Therefore, it is recommended that adding admixtures such as super plasticizer and silica fume into the mixing so that the workability will be improved.

- More investigations and laboratory tests should be done on the strength characteristics of recycled aggregate. It is recommended that testing can be done on concrete slabs, beams and walls. Some mechanical properties such as creeping and abrasion were also recommended.

- More trials with different particle sizes of recycled aggregate and percentage of replacement of recycled aggregate are recommended to get different outcomes and higher strength characteristics in the recycled aggregate concrete.

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