EXPERIMENTAL INVESTIGATION ON CONCRETE MADE WITH RECYCLED AGGREGATES

[1] T Jashnavi Krishna, [2] G Rajesh
[1]Student, [2] Assistant Professor
Department of Civil Engineering
PVKKIT

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 capacity of this project is to decide and balance the high strength concrete by using special percentage of recycled aggregates.

The study was carried out using workability test, compressive test, not direct tensile test and modulus of flexibility test. There were total of eight batches of concrete mixes, consists of each 20% increase of cast-off aggregate substitute from 0% to 100%. in addition, 100% of recycled aggregate mix batches included fly ash, water/cement ratio of 0.36 and 0.43. The workability of concrete significantly reduced as the amount of recycled aggregate increased. This was evaluated during normal slump test and compacting factor test. For power individuality, the results showed that a regularly falling in compressive strength, tensile might and modulus of stretch as the percentage of recycled aggregate used in the specimens increase

I. INTRODUCTION

1.1 Introduction of Recycled Aggregate

Recycling is the act of dispensation the used material for use in creating fresh product. The habit of natural aggregate is getting more and more intense with the advanced maturity in infrastructure area. In order to reduce the usage of natural aggregate, recycled aggregate can be used as the substitute materials. Recycled aggregate are comprised of crushed, graded inorganic particles processed from the materials that have been used in the constructions and devastation debris. These resources are usually from buildings, road and rail network, bridges, and sometimes even from catastrophes, such as wars and earthquakes.

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) confirmed that cast-off aggregate have been old in the road business for the last 100 years in Australia. They also stated that the use of recycled aggregate for the construction and treatment of local government roads has a great improve in the last five years.

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

According to Seecharan (2004), the Detroid News confirmed that in 1980s, the old concrete compressed into a fine particles was a popular road builder at Michigan, USA.

1.1 Recycled aggregate

1.3 Applications of Recycled Aggregate

Traditionally, the application of recycled aggregate is used as landfill. Nowadays, the applications of cast-off aggregate in structure areas are wide. The applications are unlike 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 improved than ordinary aggregate when old as coarse base course in roads creation. They also establish that when the road is built on the wet sub evaluation areas, cast-off aggregate will stabilize the base and present an better operational shell for concrete structure creation.

- **Embankment Fill Materials**

Market Development Study for Recycled Aggregate Products (2001) stated that recycled aggregate can be used in embankment fill. The motivation for being bright to use in guard fill is same as it is used in grainy base course creation. The embankment site is on the wet sub position areas. Recycled aggregate can steady the base and present an enhanced working surface for the left behind works.

- **pavement Blocks**

Recycled aggregate have been used as pavement blocks in Hong Kong. According to Hong Kong Housing Department (n.d.), recycled aggregate are used as classic pavement blocks. A check project had been started to test the extended – term presentation of pavement blocks made with recycled aggregate in 2002.

Figure 1.4: Typical Paving

- **Building Blocks**

Recycled aggregate used as structure blocks. Mehus and Lillestol (n.d) stated that Optiroc AS had used cast-off aggregate to manufacture the building material resonance filling blocks. The sandstone sound insulation blocks that produced had met all the necessities throughout the laboratory testing.

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

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.
- Create the concrete specimens by via dissimilar percentage of cast-off aggregate.
- Search and laboratory testing on high strength concrete with cast-off aggregate.
- Investigation the results and suggestion for additional explore area.

II. 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.

III. 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.

Figure 3.1: Balance for Aggregate Weighting.

Figure 3.2: Thermostatically restricted Oven.

3.1.3 Result and Analysis

Table 3.1: mass 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

Table 3.2:mass 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

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.

IV. 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 relationship of Canada (2003) confirmed that the workability is the ease of insertion, combining and finishing freshly concrete assorted and the degree to which it resists separation.

According to Cement Manufacturer's involvement India (n.d), a high-quality concrete must has workability in the fresh condition and also extend adequate strength. It also mentioned that there are four factors that can involve 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 excellence of water that mandatory for a mix is depended on the mix extent, types and grading of aggregate.
3. ***Grading of Aggregate***: The horizontal and curved aggregate will manufacture a more practicable concrete than the jagged bony aggregate.
4. ***Cement satisfied***: The superior workability can be obtained with the advanced cement

comfortable.

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 second-hand to conclude the workability of fresh concrete. The test is easy and contemptible. It is appropriate to use in the laboratory and also at site. even though the test is easy, but the difficult has to be done cautiously due to a huge slump may attain if there is any commotion in the procedure.

Logic bubble (n.d.) mentioned that the slump test will give a practical suggestion of how easily a mix can be seats even though it does not straight compute the work desired to compact the concrete. It also mentioned that a slump less than 25mm will point out a extremely stiff concrete and a slump that extra than 125mm will indicates a incredibly runny actual.

Australia ordinary (2002) confirmed that slump test will not specify well for the concrete with very elevated workability and also awfully low workability. This is since a very high workability concrete will misplace the figure by smooth and give way, where a awfully low workability concrete will not subside.

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 empty frustum of a cone that ready from galvanized toughen sheet. The thickness is flanked by 1.5mm to 2mm. The mould has a foot quantity, and handles on outer surface, and level internal surface. The underneath diameter of the mould is 200mm, the crown diameter of the mould is 100mm and the perpendicular diameter of the mould is 300mm.
2. ***Rod:*** A metal rod of 16mm diameter, 600mm lengthy and having a 25mm elevation of globular profile at one end with a radius of 5mm.
3. ***Base plate:*** A 3mm thickness of a straight, rigid and non permeable fabric base metal protect.
4. ***Scoop:*** A appropriate size to bring the aggregate of concrete.
5. ***Ruler:*** A proper steel ruler to determine the stature 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 located 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 packed in three layers. Each coat was around one – third of the height of the mould. every layer was being rod with 25 strokes of curved end of the bar. Each rub has rod in a identical manner that over the irritable section of the mould.
4. The exterior concrete was rolled off after the top layer has been rod. Then, take away the mould instantly by raising it gradually and cautiously in the perpendicular direction.
5. calculated the height of slump without delay. It was unwavering flanked by the height of the mould and the normal 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 second-hand on site testing since the apparatus is extremely heavy. According to Streetworks Info (n.d.), the compacting issue test gives a more correct workability of new concrete than slump test. It mentioned that the compacting factor test also identified as the “drop test”, which events the weight of wholly compacted concrete and evaluate it with the load of incompletely 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

V. 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 episode talk regarding 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 falling movement of workability when the proportion of cast-off aggregate enlarged. Table 5.1 below shows the average slump recorded during the test. Figure 5.1 below shows a graphical demonstration of slump altitude.

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

According to the result, the highest slump obtained was 90mm and the lowest slump was 64mm. The standard slump for every batch of mix was 82mm. consequently, goal slump had been achieved, where the array 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 difficulty for the situation and compaction of new 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 extremely low payable to the slump was now 64mm. The cause was since of the high inclusion capability of cast-off aggregate.

From the result obtained, it shows that the workability was receiving lesser when more cast-off aggregate were worn.

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

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. still, it shows that the strength of cast-off aggregate specimens is minor than ordinary 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								
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 5.4: Specimens after Testing

VI. 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

Investigate on the convention of waste production materials is extremely significant due to the equipment waste is steadily growing with the improved of residents and increasing of town 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.

REFERENCE

Aggregate Advisory Service, n.d., S*and and Cement*, viewed 16 May 2004, <http://www.p2pays.org/ref/17/16595.pdf>

Aggregate Advisory Service, n.d., *Save Cost*, viewed 16 May 2004,

<http://www.p2pays.org/ref/17/16595.pdf>
Aggregate and Quarry, n.d., *Quarries and the Environment*, viewed 27 April 2004, <http://www.quarrying.org.nz/environment.html>
Agg Regain, 2001, *Recycled aggregate for use as capping in housing development*, viewed 12 August 2004, <http://www.aggregain.org.uk/casestudy_detial.asp?projectID=44>
Australia Standard, 1999, '*Online Reference',* viewed on 27 Dec 2003. <http://online.standards.com.au/online/autologin.asp>
Bakoss P. S. L. and Ravindrarajah R Sri, 1999, *Recycled Construction and Demolition Materials for use in Roadworks and other Local*, viewed 4 March 2004, <http://www.ipwea.org.au/upload/final_scoping_report.pdf>
Bora Australia, n.d., *Recycled Aggregate Process*, viewed 29 Jun 2004, <http://www.boral.com.au/Atricle/nsw_recycling_process?site=biral%OA>
Building Innovation and Construction Technology, 1999, *Recycled Hits, New High*, viewed 30 August 2004, <http://www.cmit.csiro.au/innovation/1999-02/recyclestreet.htm>
Buyle-Bodin F. and Hadijieva-Zaharieva R., 2002, *Influence of industrially produced recycled aggregates on flow properties of concrete*, Materials and Structures, Volume 35, September-October 2002, p504-509.
Cement Association of Canada, 2003, *Compressive Strength*, viewed 25 August 2004, <http://www.cement.ca/cement.nsf/0/FD75CF9BCOFB1029852568A9005B082?OpenDocument>
Cement Association of Canada, 2003, *Elastic and Inelastic Deformation*, viewed 25 August 2004, <http://www.cement.ca/cement.nsf/0/52D6016170D92AD885268AB000FCF65?OpenDocument>
Cement Association of Canada, 2003, *Workability*, viewed 25 August 2004, <http://www.cement.ca/cement.nsf/0/AE12614CF961D1C852568A90055A775?OpenDocument>