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تصميم وتأهيل المنشأت

Using of Recycled Aggregate in Producing Concrete Elements

Prepared By

Fady M.Abed

Supervised By

Dr. Jehad Hamad

Dr. Mohammed Arafa

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بسم الله الرحمن الرحيم

﴿ يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنْكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ وَاللَّهُ بِمَا تَعْمَلُونَ خَبِير ﴾

المجادلة الآية 11

صدق الله العظيم

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Dedication

I would like to dedicate this work to my family specially my father who loved and raised me, my mother which I hope that she is alive now to complete my happiness, to my brothers and to my loving caring wife, for their sacrifice and endless support.

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Acknowledgement

I would like to express my deepest appreciation to my supervisor Dr. Jihad Hamed and Dr. Mohammed Arafa for there valuable advice, continuous encouragement, professional support and guidance. Hoping my thesis to get the satisfaction of Allah and you as well.

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Abstract

This thesis aimed to find the potential of using recycled aggregate as course aggregate in the production of concrete blocks and interlocks for roads.

Various percentages of recycled aggregate and natural aggregate (0%, 30%, 60% and 100%) and different water cement ratios (0.35, 0.42, and 0.50) were used to find the optimum percentage of recycled aggregate and water cement ratio to produce optimum physical, chemical and mechanical properties . The experimental test focused on physical properties of recycled aggregate; density, unit weight, sieve analysis, Los Angles test and specific gravity. Tests also performed to find the effects of the temperature on recycled aggregate by testing 60 concrete cubes (100*100*100mm) casted by using different percentages of recycled aggregate (0% , 30%, 60% and 100%) at different temperatures (20°C, 200°C, 400°C, 600°C and 800°C). Tests have also been performed on 96 concrete block samples at 7 days and 28 days for compressive strength, absorption capacity and durability test by immersion of 12 concrete blocks in sea water for 150 days to find the effects of sea water on concrete block, thus checking the expected reaction between contaminants of recycled aggregate and salts in sea water.

Test also performed on laboratory fabricated 24 interlock samples. Standard tests were performed such as: 28 days compressive strength, absorption capacity, abrasion tests, unit weight and moisture content.

It was concluded that concrete blocks can be produced using 100% recycled aggregate and used for practical application. Compressive strength of 4.3 Mpa can be produced using 100% recycled aggregate at 0.42 w/c ratio. According to the Palestinian Draft Specification, a block compressive strength of 3.5 Mpa is the minimum requirement. The reduction in interlock compressive strength when using 100% recycled aggregate content was 25 %. Interlock with 32 Mpa compressive strength can be produced by using 100% recycled aggregate. It can be used for paving sidewalks and pedestrian roads. Salt in sea water does not have any effect on block compressive strength after 150 day immersion in sea water.

The fire-resistant property of the recycled concrete is not considered to be significantly different from that of ordinary concrete. It was indicated from this results that fire resistance of recycled aggregate concrete is as good as natural aggregate concrete.

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الخلاصة

يهدف هذا البحث إلي إيجاد إمكانية استخدام ناتج مخلفات هدم المباني في إنتاج الركام المعاد تصنيعه(الحصمة) ليتم استخدامها في تصنيع البلوك وبلاط الانترلوك. و أجريت التجارب والفحوصات اللازمة لإيجاد الخواص الفيزيائية للركام المعاد تصنيعه مثل الكثافة والتدرج الحبيبي والوزن النوعي وفحص لوس انجلوس. وحتى يتم الحصول على أفضل النتائج وأفضل الخواص للعينات التي يتم إنتاجها أجريت التجارب لإنتاج عينات تحتوى على نسب مختلفة من الركام المعاد تصنيعه وتحتوى على نسب مختلفة من الاسمنت ، كما أجريت الفحوصات لإيجاد تأثير درجة الحرارة على الركام المعاد تصنيعه وذلك بفحص 60 مكعب من الباطون، و تم إجراء فحوصات على 96 عينة من البلوك مثل فحص الكسر عند 7 أيام و 28 يوم و فحص الامتصاص بالإضافة إلى فحص الديمومة الذي تم أجراءة على 12 عينة من البلوك تم إنتاجها باستخدام نسب مختلفة من الركام المعاد تصنيعه حيث تم غمر هذه العينات في مياه البحر لمدة 150 يوم لإيجاد تأثير التفاعلات المتوقعة بين الشوائب الموجودة بالركام المعاد تصنيعه والأملاح الموجودة بمياه البحر على قوة البلوك ، كما أجريت التجارب على 24 عينة من الانترلوك تم إنتاجها في المختبر وأجريت عليها التجارب اللازمة مثل فحص الكسر عند 28يوم وفحص الامتصاص و فحص البري والوزن النوعي و المحتوى المائي.

ومن خلال التجارب التي أجريت تبين انه يمكن إنتاج عينات البلوك باستخدام الركام المعاد تصنيعه حيث يمكن الحصول على قوة 4.3 باسكال عند استخدام 100% ركام معاد تصنيعه و0.42 محتوي اسمنت إلى ماء وطبقا لمسودة المواصفات الفلسطينية أنة يجب على البلوك أن يتحمل ضغط اكبر من 3.5 ميغا باسكال ، كما لوحظ من النتائج انه عند استخدام 100 % من الركام المعاد تصنيعه فان قوة الانترلوك تقل بنسبة 25% ويمكن إنتاج عينات من الانترلوك تتحمل ضغط 32 ميغا باسكال والتي يمكن استخدامها لعمل أرصفة الطرق وممرات المشاة ، كما تم استنتاج أن الأملاح الموجودة في مياه البحر ليس لها تأثير على قوة البلوك بعد غمرها لمدة 150 يوم في ماء البحر، كما لوحظ أنه لا يوجد اختلاف بين تأثير درجة الحرارة على الباطون الذي تم إنتاجه باستخدام الركام الطبيعي والباطون الذي تم إنتاجه من الركام المعاد تصنيعه وهذا يعني أن الباطون الذي تم إنتاجه باستخدام الركام المعاد تصنيعه يتحمل درجة الحرارة مثل الباطون الذي تم إنتاجه باستخدام الركام الطبيعي.

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List of Content

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المنارة للاستشارات
www.manaraa.com

المنارة للاستشارات
www.manaraa.com

List of Tables

المنارة للاستشارات

www.manaraa.com

list of Figures

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Chapter One

Introduction

1 .1 Background

Construction's and Demolition's (C&D) waste are the waste materials that are produced in the process of construction, renovation or demolition of structures. Structures include

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buildings of all types (both residential and nonresidential) as well as roads and bridges. Components of C&D waste typically include concrete, asphalt, wood, metals, gypsum wallboard and roofing**.**

Recycling and reusing aggregate from demolished building is not a new concept; Several countries have been used crushing waste aggregate for a number of years. However, the produced aggregate has been mainly limited to such a low level by using it as pipe bedding, site fill, sub base ,or as a capping layer (Khalaf and DeVenny August, 2004)

Utilization of recycled aggregate in concrete production has been increasing gradually due to the environmental and economical considerations (Otsuki et al 2007).

Wastes of concrete aggregate is considered as one of the most environmentally unfriendly pollutants because of its existence in large quantities, which produced from the demolition of old structures. Besides concrete's waste from new structures and debris of the damaged buildings in destructive earthquake. Limiting land fill space makes it necessary to find the possible uses of recycled aggregate in civil engineering applications. So, many researches concentrate on finding the properties, advantages and disadvantages of using concrete's wastes as course aggregate to produce new concrete with recycled aggregate.

1.2 Statement of the problem

The Gaza Strip is a very small area which suffers from a huge volume of construction and demolition wastes, yet lack of a natural aggregates. It is very difficult to find a landfill to dump this huge volume of waste in. Therefore, a need comes up to study the potential uses of C&D wastes as course aggregate in production interlock tiles and concrete block, and also tries to use it as another alternative source of concrete aggregate, as the unavailability of concrete raw material due to Israeli closures of ports and border, thus causing high prices of construction material. The reasons for the existence of large volume of C&D wastes in Gaza Strip are as follows;

1. The destruction of residential, official and commercial buildings by Israeli air forces during the recent several years.
2. The availability of enormous quantity of C&D wastes in settlements within Gaza, in the wake of Israel's withdrawal from these settlements in summer, 2005.

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3. Construction and demolition wastes resulting from the destruction of old building.

1.3 Aims:

The main aim of this project is to investigate the potential use of C&D wastes as a course aggregate of non-reinforced concrete material, such as interlock and concrete block.

1.4 Objectives:

- To study the properties of the produced course aggregate from Gaza's C&D wastes.
- Finding the optimum (w/c) ratio which produce the best interlock and block properties.
- To find the optimum of recycled aggregate to natural aggregate Replacement Ratio (R.R.) which produces the best interlock and concrete block properties.

1.5 Methodology

The methodology used to satisfy the objective of the research as follows:

A. Literature review

Extensive survey is performed about all available topics related to recycling C&D wastes in order to improve a background about using C&D wastes in non-structural elements, such as concrete block and interlock. Literature review concentrates on the following points:

- Historical uses and application of recycled aggregate in various structures.
- Experimental tests were preformed on recycled aggregate to check the ability of using recycled aggregate in construction application
- Recommendation that must be considered in using recycled aggregate.

- Advantages and disadvantages of using recycled aggregated in different construction applications.

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B Sample collection

Filed exploration was performed in order to collect representative sample of available recycled aggregate in the Gaza Strip area. There are many dumping sites of demolition's wastes in Rafah and Khan-Yunos. Suitable representative sample was brought from Khan-Yunos' dumping site because C&D wastes of all settlement were collected at this dumping site.

C. Aggregate tests

Experimental tests were performed on the collected recycled aggregate sample to find its mechanical and physical properties and compare it with international standard requirements

D. Preparing concrete block and interlock samples

Concrete block and interlock samples were prepared using different percentage of recycled aggregate and different w/c ratios.

E. Experimental tests on concrete block and interlock samples

Standard tests were preformed to find the mechanical and physical properties of produced concrete block and interlock samples. Comparisons between block samples produced by recycled and natural aggregate were performed to check the effect of using recycled aggregate in block properties. This comparison was also done to concrete interlock

F. Evaluation and recommendation

Evaluation and recommendation were done after performing tests and analysis results.

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1.6 Thesis organization

Thesis is divided into 7 chapters, each chapter covers a certain area as follows :

Chapter One introduces the reader to the ground feature of the subject, and presents the objective and importance of this research. Chapter Two presents literature review that covers the previous international and local efforts supported in this filed. Chapter Three presents the story of the Gaza Strip C&D wastes, its source and other research in this filed. Chapter Four presents the material used and experimental program Chapter Five presents the test results on concrete block and interlock made of recycled aggregate. Chapter 6 is the conclusions and recommendations and chapter 7 is the references. Figure 1.1 presents thesis methodology flow chart.

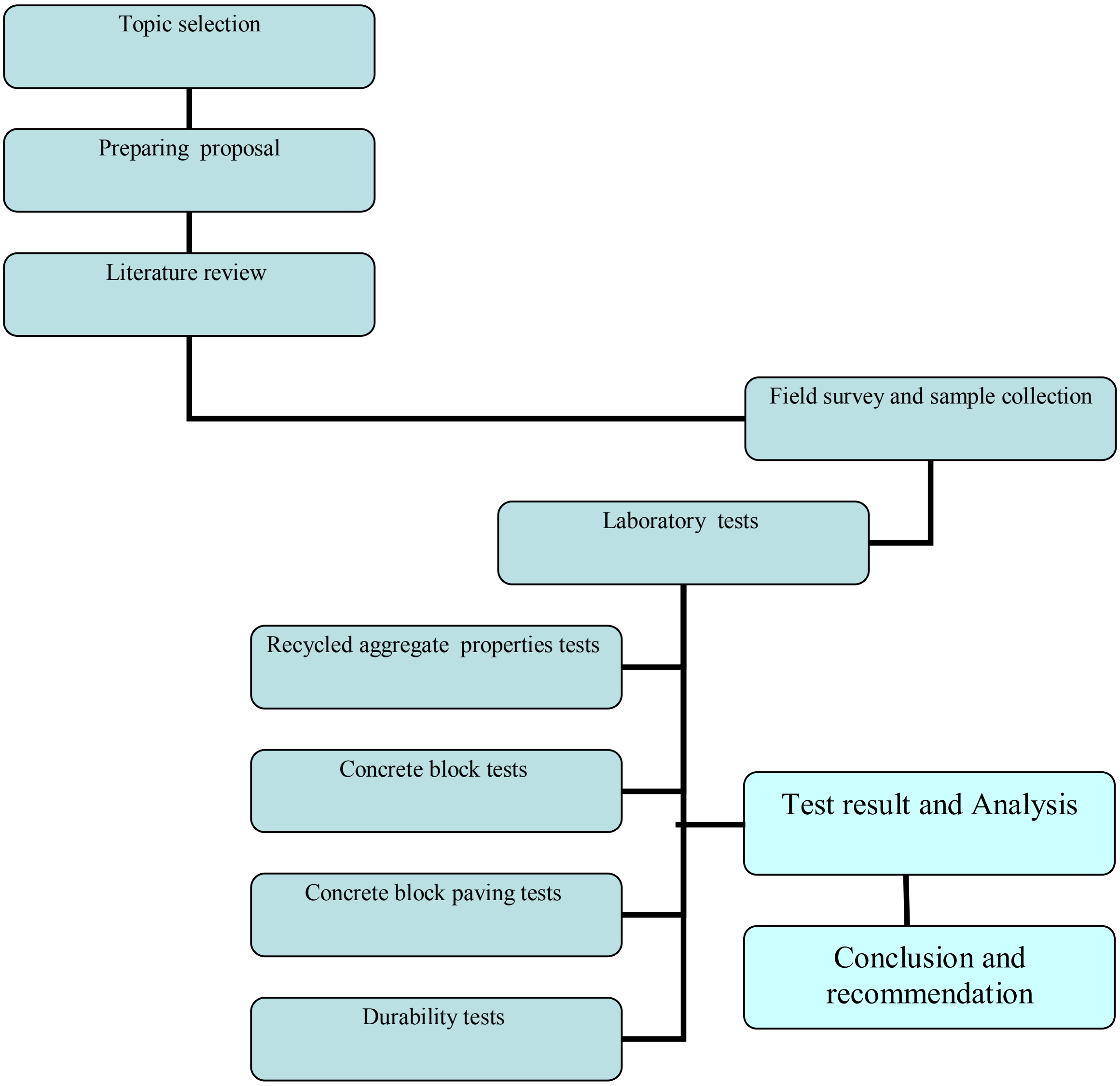

Figure 1.1 Summary of methodology flow chart

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Chapter Two

Literature Review

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2.1 Historical background

Recycling and reusing of rubbles from demolished buildings is not a new concept. Since several countries have been using crushing's wastes to produce aggregate for a number of years, the produced aggregate has mainly been limited to such a low level as it is used as pipe bidding, site fill, sub base or as a capping layer.

Concrete buildings, made of crushed brick, have been known since early Roman era. An early example is the concrete channel of Eiffel water supply to Cologne. In this structure, the binder is a mixture of lime and crushed brick dust or other pozzolans of the time (Khalaf and DeVenny, 2005)

In Germany, during the reconstruction period after the Second World War, it was necessary to satisfy an enormous demand for building materials, and to remove the rubble from the destroyed cities. The quantity of this rubble in German towns is estimated at about 400 to 600 million cubic meter. Using this rubble does not only reduce site cleaning costs, but also fulfills the need for building material. Similarly in United Kingdom, national demand for aggregate has risen steadily since the Second Word War because of the urgent need for houses, as well as the need for a new network of roads. The consumption of crushed rock and sand in the United Kingdom in 1992 was 240 million ton, obtained mainly by quarrying and dredging (Kalaf and DeVenny 2005)

To reuse the martial, rubble recycling plants were set up in Federal Republic of Germany. These plants produced around 11.5 million cubic meter of crushed brick aggregate by the end of 1955, with which 175000 dwelling units were built. By the end of 1956, statistics showed that 85% of all building rubble in the Federal Republic of Germany has been cleaned. Which means that there was no longer such a need for recycling demolition material (Hansen, 1992).

A recent European survey showed that 25% of wastes come from the demolition of buildings and roads. 90% of it is recyclable, but only 30% is recycled. According to the U.S Environmental Protection Agency (EPA), 215 million tons of municipal solid waste is generated in the United States from C&D waste per year. This made up primarily of concrete, asphalt concrete, wood, gypsum, demolition material and asphalt shingles

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generated from road construction and high way maintenance, building renovation demolition of building and other structure. (Khalaf and DeVenny 2004)

A presented report in 1999 to the European Commotion estimated the amount of non recycled construction wastes as 130 million ton per year. The required area for land filling this amount of wastes is equivalent to the accumulation of waste, 1.3 m high over the entire central Paris area (Katz, 2004)

Within the European Union, the C&D wastes come to at least 180 million tons per year. Roughly 75% of the wastes is disposed to landfills, despite its major recycling potential. However, the technical and economic feasibility of recycling has been proven, thus enabling some Member States (in particular Denmark, The Netherlands and Belgium) to achieve recycling rates of more than 80%.On the other hand, the South European countries recycle very little of their C&D waste. In Italy, every year more than 20 million tons of C&D wastes are produced. They are mainly constituted of debris coming from demolished structures made of masonry or reinforced concrete. At present, only 10% of this material is recycled and the exceeding part is disposed of in landfills for inert materials since its is illegally disposed of by other means (Corinaldesi and Moriconi, 2008)

The transformation from a conventional consumption based society to a sustainable society is urgently required in Japan due to the pollution of the natural environment. And the exhaustion of the natural resources and the decreasing capacity of the final wastes' disposal facilities. Currently, the construction industry produces 19% of the total volume of industrial wastes (75 million tons/year), which signals a need for reuse to protect the environment. Recycling of concrete blocks, which make up 37% of construction waste, is an important issue to be promoted. As regards recycling technology of turning concrete blocks into aggregate for concrete, many research have been carried out and the results have long been available. Based on the Comprehensive Research and Development Project conducted by the Ministry of Construction of Japan (Eguchi et. al. 2006).

2.2 Crushing and grading

To achieve the most ` grading curve for concrete aggregate, a series of crushers must be used with the return of any oversize particle to the repetitive crusher. The best particle

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shape is usually achieved by primary crushing and then secondary crushing, but from an economic point of view , a single crushing process is usually most effective.

Hammer and impact crushers are usually used for reducing the material into the required particle size in a single operation.

Care should be taken when crushing brick material because more fines are produced during the crushing process than during the crushing of concrete or primary aggregates.

A sieve analysis using a range of sieves is used to produce a grading curve for either individual aggregate fractions or their combination. This is usually plotted on a logarithmic scale as the total amount of material passing a particular sieve versus sieve size. These curves can be used to monitor the size of aggregates being used in concrete production. This is done so as to minimize the voids content within the concrete mix. (Khalaf and DeVenny, 2004)

Grading curves do not take into account particle shape, but this influences the voids content of concrete.(ILL ston,1992).

This is because more rounded particles will pack more efficiently with the addition of cement paste, and will therefore produce concrete with a lower voids content. As crushed brick aggregate has a fairly angular appearance compared to an aggregate such as crushed granite, the aggregate will not pack as efficiently. (Khalaf and DeVenny, 2004)

Figure 2.1 Construction and demolition waste crusher

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2.3 Application of recycled aggregate

Crushed concrete can be reused in new construction as road and railroad base material, fill, or pavement constituents. In some applications, recycled concrete may be used in place of aggregate for drainage layers and sub-bases. Other potential uses include ballast, drainage, erosion control and filter material. Finally, crushed concrete can also be used as a neutralizing agent in a variety of applications. The reuse of crushed concrete as aggregate in high-grade concrete, however, has up to now been restricted by a lack of standards, and a lack of experience and knowledge in working with the materials. (Public Works Technical Bulletins 2004)

Table 2.1 illustrates the composition of demolition material and classifies it according to its final uses for different applications.

Table 2.1 Recycled aggregate using (Holcim Ltd, 2007)

Material	**Process**	**End use**
Plain concrete	crushed	Aggregate
Fresh concrete	Washed to remove cement and recover aggregate	Aggregate
Reinforced concrete	1.Crushed and steel bars removed 2. Steel recycled	1.Crushed concrete reused as aggregate 2.New reinforcement steel
Clay bricks and roof tiles	1. Cleaned 2. Crushed 3. Pulverized	1.Reused for masonry 2.Aggregate 3.Mixed with lime to produce mortar
Calcium silicate bricks	1. Cleaned 2. Crushed	1.Reused for masonry 2.aggregate 3.Recycled into new calcium silicate bricks
Natural stone masonry	1. Cleaned 2. Crushed	1.Reused for masonry 2.Aggregte
Natural stone slabs	1. Cleaned 2. Crushed	1.Flooring cladding 2.Aggregate
Ceramic tiles	1. Cleaned 2. Crushed	1.Flooring cladding 2.aggregate
Asphalt paving	1. Crushed and cold-mixed 2. Crushed and hot-mixed	1.Road base, fill material 2.Road construction
Mixed DW (ABC=asphalt, bricks ,concrete)	Crushed	Road base, fill material
Steel	1. Cleaned 2. Recycled	1.Reused steel components 2.New steel components

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Aluminum	1. Cleaned 2. Recycled	1.Reused alum components 2.New alum components
Timber beams ,door, etc.	Cleaned	Reused as beams, doors etc .
Timber boards	Cleaned	1. Reused as shuttering and other products. 2.Feedstock for engineered woods.
Timber (miscellaneous items)	1. Cut to suitable sizes 2. Chipped	1.Firewwood , co-processing 2. Landscape mulch , mulch , soil conditioner , boiler fuel , etc.
Plastics	Recycled	New products
Gypsum plasterboard	1. Cleaned 2. Crushed 3. Recycled	1. Reuse as boards 2. Soil conditioner 3. New gypsum products
Glass	1. Cleaned 2. Crushed 3. Recycled	1. Reused for windows. mirrors, etc. 2. Aggregate 3. New products
Electrical and sanitary fixtures	1. Clean 2. Separate unusable items into individual components to facilitate recycling	1. Reused 2.New products
Insulation	1. Clean 2. Recycle	1. Reuse 2. New products
Packaging materials	Recycle	New packaging material

Crushed concrete can be reused in new construction as road and railroad base material, fill, or pavement constituents. In some applications, recycled concrete may be used in place of aggregate for drainage layers and sub-bases. Other potential uses include ballast, sub-ballast, drainage, erosion control and filter material, and the main practical application of recycled aggregate is illustrated as follows;

1. Concrete Kerb and Gutter Mix

Recycled aggregate has been used as concrete kerb and gutter mix in Australia.

According to Building Innovation & Construction Technology (1999), A 10 mm recycled aggregate and blended recycled sand are used for concrete kerb andgutter mix in the Lenthall Street project in Sdyney. (Nelson and Shing Chai, 2004)

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2. Granular Base Course Materials

A base course is defined as the layer of material that lies immediately below the wearing surface of a pavement. The base course must be able to prevent overstressing of the sub grade and to withstand the high pressures imposed on it by traffic. It may also provide drainage and give added protection against frost action when necessary. Recycled aggregates can be used as granular base and sub-base in road construction.

In many applications, recycled aggregate will prove to be superior to natural aggregate for use as granular base. An estimated 85 percent of all cement concrete debris that is recycled is used as road base due to its availability, low transport cost, and good physical properties. (Nelson and Shing Chai, 2004)

3. Interlock

Recycled aggregate has been used as interlock in Hong Kong. According to Hong Kong Housing Department, recycled aggregates are used as typical interlock. A trial project had been started to test the long – term performance of interlock made with recycled aggregate in 2002.

4. Building Blocks

Concrete blocks are made by mixing Portland cement, sand, and other aggregates with a small amount of water and then blowing the entire mixture into molds. The major component material of concrete block (sand and various coarse aggregates) account for as much as 90 % of its composition. Recycled material such as crushed concrete can be used for some portion of the aggregate in block. Concrete block offers an advantage because there is little waste. Any unused block can be recycled or saved for future projects rather than being disposed of. (Nelson and Shing Chai, 2004)

2.4 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, 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 more water than the smooth and rounded compact aggregate when producing a 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. (Nelson and Shing Chai, 2004)

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Roughly textured, angular, and elongated particles require more water to produce workable concrete than smooth, rounded compact aggregate. (U.S. Army Corps of Engineers, 2004)

- **Quality**

The quality is different between natural aggregate and recycled aggregate. The quality of natural aggregate is based on the physical and chemical properties of sources sites, where recycled aggregate depends on contamination of debris sources.

Natural resources are suitable for multiple products and higher products, and have larger marketing area, but recycled aggregate has limited product mixes, and the lower product mixes may restrain the market. (Nelson and Shing Chai , 2004)

Recycled concrete from buildings may be contaminated by sulfates from plaster and gypsum wallboard, which creates a possibility of sulfate attack if the recycled aggregates used in concrete are accessible to moisture (Buck 1972).

- **Density**

The density of the recycled concrete aggregate is lower than natural aggregate when compared with natural aggregate. Recycled concrete aggregate has 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.

The lightweight, porous cement mortar attached to recycled concrete aggregates causes crushed concrete aggregates to have a lower specific gravity and higher water absorption than comparatively sized natural aggregates.

The lower compacted unit weight of recycled aggregate, compared with conventional mineral aggregates, results in higher yield (greater volume for the same weight), and is therefore economically attractive to contractors. (U.S. Army Corps of Engineers, 2004)

- **Strength**

The strength of recycled aggregate is lower than natural aggregate. This is due to the weight of recycled aggregate which is lighter than natural aggregate. This is the general effect that will reduce the strength of reinforcement concrete.

- **Location**

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

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and roads. The locations of recycling plants are dependent on where the structures are demolished. The recycling process is often located in the urban area. (Nelson and Shing Chai, 2004)

Figure 2.2 : Recycled concrete aggregate

2.5 Properties of recycled aggregate

2.5.1 Physical properties.

Recycled concrete aggregate looks like crushed stone. However, crushed concrete has many physical properties that vary from those of natural aggregates. In general, crushed concrete particles are more angular and have a rougher surface texture than natural aggregate. Roughly textured, angular, and elongated particles require more water to produce workable concrete than smooth, rounded compact aggregate

2.5.2 Chemical properties.

One of the main issues surrounding the use of recycled concrete aggregate in concrete production is the potential for reaction between the recycled course aggregate and alkaline water. Alkali-silica reaction results in volumetric expansion, in which there is a high probability of internal fracturing and premature deterioration of the concrete. Where alkali-silica reactivity is of concern, the potential for deterioration should be evaluated .

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Chloride ions from marine exposure can also be present in recycled concrete aggregate.
Because of the use of deicing salts as a mechanism to control development of ice on pavement, there is a strong possibility that chloride ions will be present in recycled concrete aggregate. The presence of chloride ions in Portland cement concrete can adversely impact the reinforcing steel within concrete. Reinforcing steel in the presence of chloride ions will react to form iron oxide or rust. If the formation of iron oxide persists, there is a high probability of delaminating of the concrete structure. Since total elimination of all deleterious contaminants is not practical, experimentation is required to determine acceptable levels and to eliminate unnecessary processing cost while providing a quality product.(Public Works Technical Bulletins 2004)

2.6 Characteristics of recycled aggregates

2.6.1 Gradation

The particle size distribution or grading of an aggregate has an important factor that effectively influences on the properties of fresh and hard concrete. When concrete elements are produced using well graded aggregate, this will decrease void ratio between aggregate particles, which produce hard and dense concrete with high compressive strength.

2.6.2 Water absorption

Water, as a primary agent, is able to create and degrade natural and artificial materials, like concrete. It is also a central factor behind most of the problems regarding concrete durability, as water works as a transport vehicle for aggressive ions and as a cause of chemical processes causing physical and mechanical degradation of concrete structures.

Water, ions, and gas penetrating the concrete also can change the concrete degradation kinetics during the structure service life. This investigation shows that it is possible to evaluate the influence of recycled aggregates to the depth of carbonation of concrete and that CO2 gas penetration depends on the cement’s composition, porosity, and aggregate mineral composition (Levy and Helene 2004)

Additionally, the absorption capacity of the recycled coarse and fine aggregate rises to 5% and 10%, respectively, as compared to those of normal, coarse and fine aggregates which are about 1% and 2%, respectively. Such high absorption capacity will lead to greater water demand (Tsung-Yyeh Tu et al, 2006)

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2.6.3 Porosity

The porosity of aggregate, and its permeability and absorption are very important factors in influencing aggregate properties such as the bond between it and the cement paste, the resistance of concrete to freezing and thawing, as well as its chemical stability and resistance to abrasion. The specific gravity of the aggregate also depends on its porosity; as a result, the yield of concrete for a given weight of aggregate is affected.(Khalaf and DeVenny, 2004)

2.6.4 Specific gravity

The specific gravity of recycled aggregates is lighter than that of natural aggregates due to the existence of loose paste and bricks in construction and demolition wastes. As a result of the soil and brick content in recycled aggregates, high porosity is created in recycled aggregates and recycled aggregates coated with loose-bound mortar (Tsung-Yyeh Tu et al, 2006)

2.6.5 Compressive strength

When the natural aggregate is replaced by 20% of the recycled aggregates from old concrete or old masonry, the resulting recycled concrete will likely present the same, and sometimes better, behavior than the reference concrete made with natural aggregates in terms of the properties studied in this investigation. This fact justifies the efforts to use these concretes, which can contribute to the preservation of the environment and can achieve the same final performance with probably less cost than ordinary concretes. (Levey and Helene, 2004)

2.6.6 Workability

Concrete made with recycled aggregates (20%, 50%, and 100% replacement) from old masonry or from old concrete can have the same fresh workability and can achieve the same compressive strength of concrete made by natural aggregates in the range of 20–40 MPa at 28 days (Levey and Helene, 2004)

2.7 Durability tests

2.7.1 Carbonation depth

The carbonation depth decreases when the amount of recycled aggregates increases, presenting a better behavior when this replacement is 20% or 50%, mainly for the recycled coarse and fine masonry aggregate. When using masonry or recycled concrete aggregates, also with 100% replacement, the carbonation depth is still lower, compared

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with reference concrete made by natural aggregates. The explanation of this can have support in the highest cement content of recycled concretes to achieve the same compressive concrete strength of natural aggregates concrete. (Levy and Helene, 2004)

The chloride penetration and carbonation depth increase with the increase in water binder ratio; chloride penetration and carbonation depth of recycled aggregate concrete area slightly higher than those of normal aggregate concrete. This is due to the presence of old interfacial transition zone and adhesive mortar in recycled aggregate, which make recycled aggregate more permeable than normal aggregate concrete (Otsuki N. et. al. 2003)

2.7.1.2 Testing of carbonation depth

A very simple test of carbonation is to spray the concrete surface with the chemical indicator solution which changes the color. According to the alkalinity of the concrete, a solution of phenolphthalein in dilute alcohol is usually used because it has a very strong pink colour that is visible on any kind of concrete, which has retained its alkalinity but is colorless on concrete, which is no longer alkaline enough to protect the steel from rusting. Change in the color of phenolphthalein takes place as pH increase from 8.2 to 10 this conveniently corresponds with the pH needed to protect steel by passivation.

To test whether concrete has carbonated, the tested surface must be freshly broken and then sprayed with pH indicator solution. A hammer and sharp cold chisel can be used to remove part of the concrete's surface for this test, or a piece can be broken out at the corner section with a hammer. (Strecker P. P. 1987)

2.7.2 Fire resistance

Concrete is considered to have good properties with especial respect to fire resistance. The material is able to perform for a relatively long period of time, and no toxic fume are emitted when it comes in contact with fire. Steel performs less well if subject to fire. So concrete is often used as a protective material in a typical fire. Temperature reaches about 500°C in about 10 min and 950°C in 1 h, so concrete must be able to withstand rapid temperature rise as well as a high final temperature (Khalaf and DeVenny, 2004)

Water content of the recycled concrete was expected to be higher than that of ordinary concrete due to the greater water absorption of the recycled coarse aggregate.

Generally speaking, the higher the water content, the higher the potential of the concrete spilling is expected in fire.(Eguchi K. et al 2007)

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2.7.2.1 Test of fire resistance

The high temperature test is designed to determine the ability and duration of all the concretes produced in this investigation in order to maintain compressive strength, when exposed to high temperatures. Fifteen 100 mm test cubes were taken from each mix for strength tests at different temperatures. Three cubes for each temperature were required from each different mix to test for compressive strength, as well as three cubes that were crushed at room temperature to act as a control. Test cubes were placed in a kiln and subjected to designate temperatures of 200, 400, 600 and 800 C for a period of time. The cubes were tested hot within 15 min after removal from the kiln for compressive strength. (Khalaf and DeVenny, 2004)

Another test was used to evaluate fire resistant property. In the test, a cylindrical specimen of 15 cm diameter and 30 cm length was heated at the conditions specified in ‘‘Method of Fire Resistance Test for Structural Parts of Building’’. The concrete specimen had water–cement ratios of 50% and 60% and varying replacement ratios ranged from 0% to 100%. According to the test results, the water content after two months curing in the air (at the time of the heating test) was 4.3–4.7% for the ordinary concrete. The water content of recycled concrete was higher as the replacement ratio increased and was 6.9–7.1% at 100% replacement ratio. However, spalling did not take place in any of the samples. Thus, the .fire-resistant property of the recycled concrete is not considered to be significantly different from that of ordinary concrete. (Eguchi K. et al 2007)

2.8 Production of interlock

2.8.1 Fabrications of interlock

The interlock were fabricated in steel moulds with internal dimensions of 200 mm long, 100 mm wide, and 60 mm high. The mix was poured into the mould in three layers of about equal depth. After each of the first two layers was poured, compaction was applied manually using a hammer and a wood stem. After the third layer was poured, a compressive force at a rate of 600 kN/min was applied for about 50 s to mechanically compact the mix within the mould. Excess materials were then removed with a trowel. Finally, a compaction force was applied at the same rate for 60 s. The fabricated blocks, in the steel moulds, were covered by a plastic sheet and left at room temperature and relative humidity of about 50%. The interlock were then demoulded one day after

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casting and were cured in water until tested.(Poon and Chan 2007 , Poon et al , Poon and Chan 2006)

2.8.2 Test methods of interlock

The replacement of course and fine natural aggregate by recycled concrete aggregate can reach 50% without registering a reduction in compressive strength of paving block. The durability performance of the resulting interlock using recycled concrete aggregate were also satisfactory (Poom and Chan 2006)

A range of tests were carried out to determine the density, water absorption, 7-day and 28-day compressive strengths, tensile splitting strength, skid resistance and abrasion resistance of the block specimens. (Poon and Chan 2007 , Poon et al , Poon and Chan 2006)

2.8.3 Density test

The density of interlock was determined using a water displacement method as per BS 1881 Part 114 for hardened concrete.

2.8.4 Water absorption test

Water absorption values were determined in accordance with AS/NZS 4456.14 ‘‘Australian and New Zealand Standard ’’ and were expressed as a ratio of the mass of the absorbed water of an immersed specimen to the oven dried mass of the same specimen. The absorbed water was measured after immersing the block specimens in water at room temperature for 24 h. (Poon and Chan 2006)

2.8.5 Compressive strength test

The compressive strength was determined using a compressive testing machine with a maximum capacity of 3000 kN. The load, increased at a rate of 400 kN/min, was applied to the nominal area of interlock. Prior to the loading test, the interlock were soft capped with two pieces of plywood. The compressive strength was calculated by dividing the failure load by the loading area of the interlock. (Poon and Chan 2006)

2.8.6 Tensile splitting strength test

The tensile splitting strength was determined in accordance with BS 6717. The test was carried out along the longest splitting section (i.e., the length) of the block specimen. Prior to the test, the block specimen was concentrically packed with two steel packing pieces on the top and bottom faces in contact with the platens of the loading machine. A

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load was then gradually applied at a constant rate of 9 kN/min. The test was terminated when the specimen split into two halves. The failure load was recorded and the tensile splitting strength was calculated based on the failure load. (Poon and Chan 2006)

2.8.7 Abrasion resistance test

The abrasion resistance was determined by abrading the surface of the block specimen with an abrasive material under controlled conditions as specified by BS 6717. The dimension of the groove resulting from the abrasive action was used to measure the abrasion resistance of interlock; a smaller groove indicated a better resistance to abrasion.

2.9 Studies of Palestinian Recycling Demolition Waste

Although the age of recycling C&D wastes researches in Gaza does not exceed one decade, many research in this subject were performed but it is still limited. This research covers the recycled aggregate characteristics, using recycle aggregate in road application as base course, asphalt mix, in producing concrete and in producing hollow blocks.

2.9.1 Characteristics of Recycled Aggregate

Specific gravity of recycled aggregate concrete is relatively less than natural aggregate because of existing cementations material which is high porous material, and because of the rapid absorption of the recycle aggregate the workability of the fresh concrete is low. Especially after 15 min of casting process (Subaih et. al, 2005)

The specific gravity of the tested recycled course aggregate samples ranges between 2.35 and 2.44, which is lower than crushed natural rock stone. It is noticed that the natural aggregate has a higher specific gravity due to the soundness of the natural rock stone and the lower porosity. Recycled aggregate samples have higher absorption value, greater than 5% in general, compared to natural materials which have a maximum absorption value of 2.2-3.8%. It is observed that the demolition samples have absorption values higher than crushed concrete samples. This is expected, because the demolition samples include more impurities; plasters, tiles, blocks, etc. which increase the absorption capacity (Rustom, 2005)

The dry density of recycled aggregate is about 0.85 of the dry density of natural aggregate (Zuhud, 2008)

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2.9.2 Road Application

The CBR ratio at 100% was 186.6 for demolition samples and 186.1 for crushed concrete samples. Comparably with the local base course that is ranged between 100 and 130, the CBR values were high due to the large quantity of compendious materials (Rustom, 2005)

2.9.3 Concrete Application

Concrete made with recycled aggregate has a compressive strength of about 22 % to 32% less than the strength of the concrete made with natural aggregate (Khatib et. al, 1999).

The recycled aggregate concrete has a convenient compressive strength, flexural strength and bond strength, which means convenient concrete for structural elements in concrete structural. (Zuhud, 2008)

2.9.4 Hollow Block Application

Concrete Hollow Blocks made with recycled aggregate has a compressive strength about (12 – 21)% less than that of CHB made with natural aggregate. For the same compressive strength, the cost of with recycled aggregate is less than the cost of those with natural aggregate. (Qrenawi et. al, 2003)

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Chapter Three

Recycled Aggregate in Gaza

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3.1 Introduction

The true age of Gaza demolition wastes problem did not begin at the beginning of the year 2005, but it started when the Israelis military tended to destroy the houses of wanted Palestinians during the Intifada 1987. This problem began to increase and became urgent to the extent that it has become phenomenon worth of studying in order to find the suitable solution .This problem became complex at Al-Aqsa Intifada 2001 when the Israeli air force attacked all public buildings and Palestinian Authority Headquarters in the Gaza Strip. After the Israeli withdrawal from Gaza settlements in 2005, and as a result of the Israel policy that destroyed all residential, industrial and public buildings in these settlements, huge quantities of waste have been crouching everywhere . This new quantity added a big quantity of C&D wastes to the existing locally dumped. The history of Gaza demolition wastes' problem didn't stop at this point, but it opened a new stage at the end of the years 2008 and 2009, when Israel waged war on Gaza population. This war extended to about 22 days of continuous destruction of public, residential and also industrial building. According to Palestine Central Bureau of Statistics Estimation, 22000 buildings were subject to complete and partial destruction, about 15 % of all Gaza buildings.

Figure 3.1 Collection recycle aggregate

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This demolition waste was estimated according to UNRWA (2009) reports as 600000 tons, and this quantity is added to the previous available construction and demolition quantity to cumulate on Gaza dumping landfills and occupy large area on the Gaza Strip

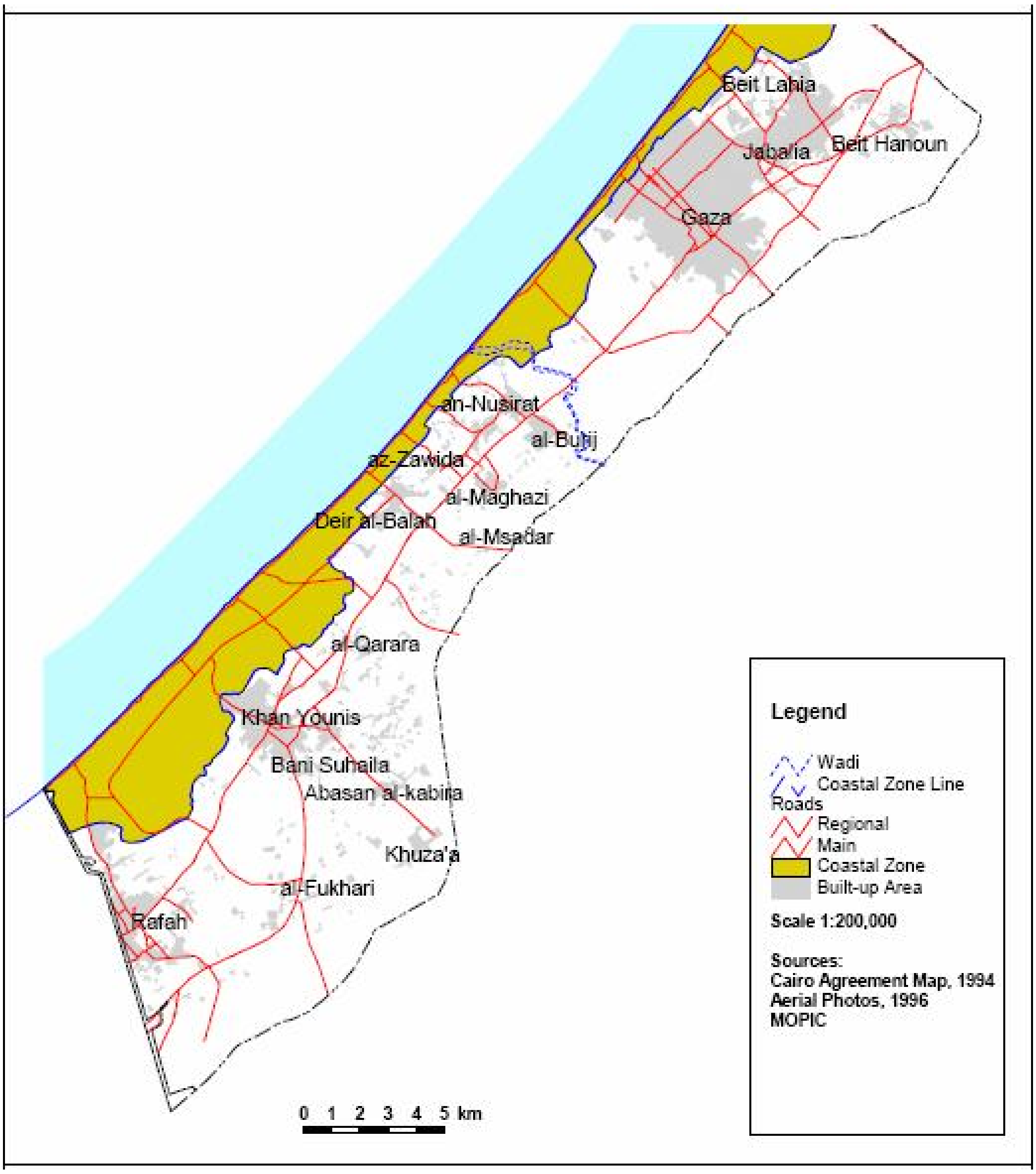

Figure 3.2 The Gaza Strip map

The Gaza strip is considered as respectively small area of about 365 km² ; this means that we are suffering from emergency problem, and efforts must be exerted to find a quick and practical solution.

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3.2 Reasons that may hold back recycling progress in Gaza

1. Lack of technology ,standard and specification for using this material
2. Recycled material does not provide the same strength, characteristics and durability as natural material.
3. Lack of market for recycle C&D material.
4. Lack of public awareness about the ability of using recycled material in their projects
5. Lack of crushing machines
6. Lack of public awareness of construction and demolition problems
7. Lack of funds for recycling projects

3.3 Negative impact of construction and demolition waste problem

1. The existence of demolition waste permanently at land fills will produce air pollution dust to smell of decaying material .
2. Reduction of area for demolition wastes
3. Surrounding areas' loss to its actual value due to existing demolition waste
4. Recycling of C&D waste will reduce the depletion of natural resource

3.4 Benefits of recycling construction and demolition waste

1. Environmental impact
2. Reduction of landfill area
3. Saving natural resource
4. Reducing cost of new construction
5. Saving energy for producing new material
6. Creating new jobs

3.5 Source and quantities of construction and demolition waste in the Gaza Strip

Although there are many reports which register quantities of construction and demolition wastes in the Gaza Strip, yet these reports depend on rough estimation, and there is no research based on actual field measurements of demolition wastes. This as a results of Gaza special situation (Israeli occupation and the continuous military Israeli attracts on Gaza infrastructure and buildings). However, there are many governmental, non-governmental and international associations which present reports about construction and demolition waste in the Gaza Strip like: Ministry of Civil Affairs , Islamic University of Gaza and UNRWA, and this estimation can be presented as follows:

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1. According to a survey performed by the Islamic University of Gaza in 2002, more than 1 million m^3 of construction and demolition waste was distributed over more than 21 main sites in the Gaza Strip.
2. The Ministry of Civil Affairs estimated the quantity of construction and demolition wastes which is generated as a result of destroying Israeli settlements during withdraw from the Gaza Strip by 356000 tons – 178000m3 .
3. Construction and demolition waste which results from normal population which presented at table 3.1

Table 3.1: Expected amount of solid waste in Palestine

Area	Weight of Solid Wastes Ton/Day		Weight of Waste 1000 Ton/Year		Amount of Solid Wastes 1000 m^3	
Year	1994	2010	1994	2010	1994	2010
Gaza Strip	400	1500	146	547.5	438	1643. 5
West Bank	600	2400	219	876	657	2628
Total	1000	3900	365	1423.5	---	4271 .5

4. After 2009 Israeli War on Gaza population which destroyed about 15 % of Gaza buildings , the construction and demolition waste estimated by reports from UNRWA was around 600000 tons

Table 3.2 : Gaza infrastructure destruction in 2009 war

Establishment	**Number**	**Losses Coste $ Million US**
Completely destroyed housing units (1)	4,100	200.0
Partially damaged buildings and housing units (1)	17,000	82.0
Destroyed and Damaged Mosques (1)	92	12.0
Destroyed Education Buildings (1)	29	9.7
The Headquarter of Security (2)	60	12.2
Ministries Compound (2)	1	25.0
Ministries Buildings (2)	16	43.5
Bridges (2)	2	3.0
Municipality and Local Authority Headquarter (3)	5	2.3
Fuel Station (1)	4	2.0
Furniture, Vehicles, equipment of destroyed buildings (1)	-	1.0
Water and Wastewater Network (4)	10	2.4

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Agriculture Land, Intermediate Consumption & Infrastructure	-	170.0
Destroyed Ambulances and Civil Defense Vehicles (1)	20	1.5
Electric Power Distribution (1)	10	10.0
Length of Road (km)	50	2.0
Factories, shops Exchange, metal workshops and other commercial facilities (facility).	1500	19.0
Homes, factories, and workshops' fences (1)	-	5.0
Others direct Losses (1)	-	22.0
Total Direct losses		**624.6**
Costs of removal of rubble and workers wages (1)	-	600
Total losses of infrastructure and Building		**1224.6**

(1) Palestine Central Bureau of Statistics Estimation
(2) Palestine Central Bureau of Statistics Estimation based on Preliminary Estimation of Palestinian Contractors Union
(3) Ministry of Local Government Estimation
(4) Palestinian Water Authority Estimation

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Chapter Four

Material and Experimental Program

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4.1 Testing program

1- Block test

Block samples were prepared using 12 different concrete mixes, each mix differs from the other in w\c ratio and percentage content of recycled aggregate. These different samples were divided into 12 sets (A_1, A_2, ….. and A_{12}). Five tests were conducted for each set as listed below :

1. Concrete block compressive strength test at 14 day curing
2. Concrete block compressive strength test at 28 day curing
3. Concrete block unit weight
4. Concrete block density
5. Concrete block absorption capacity

2- Interlock test

Interlock samples were prepared using 4 different concrete mixes, each mix has different w\c ratio and different percentage of recycled aggregate content . These sample were fabricated at IUG Material and Soil Laboratory . Special steel moulds were manufactured for the casting process . Concrete mix was fabricated at these moulds then applied to 600 KN/min compressive force for 60 seconds. Interlock sample were divided into 4 sets (B_1, B_2, B_3 and B_4). Five different tests were performed to each set

1. Concrete interlock compressive strength test at 28 day curing
2. Concrete interlock unit weight
3. Concrete interlock density
4. Concrete interlock absorption capacity
5. Abrasion test

3- Fire resistance test

Concrete 100 mm cubic samples were prepared using different concrete mixes. Each mix has different percentage content of recycled aggregate and 0.42 w/c ratio was used . These samples were divided into 4 sets (C_1, C_2, C_3 and C_4) . Fire resistance tests were conducted to each set at different temperature as listed below :

1. Compressive strength test for sample at T = 20°C (room temperature)
2. Compressive strength test for sample at T = 200°C
3. Compressive strength test for sample at T = 400°C
4. Compressive strength test for sample at T = 600°C
5. Compressive strength test for sample at T = 800°C

4- Sea water test

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Concrete block samples using 4 different mixes were prepared, each mix has different percentage content of recycled aggregate and 0.42 w\c ratio was used . These samples were divided into 4 sets (D1, D2, D3 and D4) . Block samples were immerged in sea water for 150 days, then tested at compressive strength test .

Table 4.1 Test program of research samples

NO. of Concrete Block Tests													
w/c	0.35				0.42				0.50				Total
R.R	0%	30%	60%	100%	00%	30%	60%	100%	0%	30%	60%	100%	
Set type	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	
No.of different tests	5	5	5	5	5	5	5	5	5	5	5	5	60

NO. of Interlock Block Tests					
w/c	0.42				Total
R.R	0%	30%	60%	100%	
Set type	B_1	B_2	B_3	B_4	
No. of different tests	5	5	5	5	20

NO. of Tests of Fire Resistance					
w/c	0.42				Total
R.R	0%	30%	60%	100%	
Set type	C_1	C_2	C_3	C_4	
No. of different tests	5	5	5	5	20

NO. of Test of Block at Sea Water					
w/c	0.42				Total
R.R	0%	30%	60%	100%	
Set type	D_1	D_2	D_3	D_4	
No. of different tests	1	1	1	1	4

4.1.1 Tests samples

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Table 4.2 and figure 4.1 show the tests which were performed. These tests were divided into four types.

1- **Aggregate properties test**

In this type of test, properties of recycle aggregate, natural aggregate and fine aggregate were investigated to find its properties. These tests were; sieve analysis, specific gravity, moisture content, unit weight, absorption capacity and Los Angeles test .

2- **Concrete block test**

In this stage 108 concrete sample test were prepared by using different percentage of recycled aggregate (0%,30%60%and 100%) and different w\c ratio (0.35, 0.42 and 0.50). These tests were: compressive strength 14 and 28 days, unit weight, absorption capacity and specific gravity.

3- **Concrete interlock test**

In this stage 12 interlock block samples were prepared using different amounts of recycled aggregate (0%, 30%, 60% and 100%) and 0.42 w\c ratio. These tests were: compressive strength 28 days, absorption capacity and abrasion test .

4- **durability test**

in this stage two type of test were preformed

- Fire test : In this test 60 cubic sample 100*100*100 mm were prepared using different contents of recycle aggregate (0%, 30%, 60% and 100%) and w\c 0.42 and the these samples were tested for compressive strength at 28 days after subjected to variable temperatures (20˚C, 200̊C, 400̊C, 600̊C and 800̊C)
- Sea water test : In this stage 12 concrete block sample were prepared using (0%, 30%,60%and 100%) recycled aggregate content and at w/c 0.42, then these samples were immersed for 150 days in sea water and tested by compressive strength

Table 4.2 No. of Tested samples

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Aggregate properties test

Recycled Natural and fine aggregate properties tests	Sieve analysis	Specific Gravity	Unit Weight	Absorption Capacity	Moisture Content	Los Angales

Concrete block test

water cement ratio %	0.35				0.42				0.50				Total
Recycled aggregate to natural aggregate ratio (R.R)	R.R				R.R				R.R				
	0%	30%	60%	100%	00%	30%	60%	100%	0%	30%	60%	100%	
Compressive 14,28 day test	6	6	6	6	6	6	6	6	6	6	6	6	72
density and absorption and unit weigh	3	3	3	3	3	3	3	3	3	3	3	3	36
Sea water 150 days compressive strength test					3	3	3	3					12

Concrete interlock samples

Compressive 28 day test					3	3	3	3					12
Density and absorption and unit weigh and abrasion Test					3	3	3	3					12

Fire resistance test for cubic (100mm) samples

Room temperature =20℃					3	3	3	3					12
Temperature = 200℃					3	3	3	3					12
Temperature =400℃					3	3	3	3					12
Temperature = 600℃					3	3	3	3					12
Temperature =800℃					3	3	3	3					12
Total No. of samples													**204**

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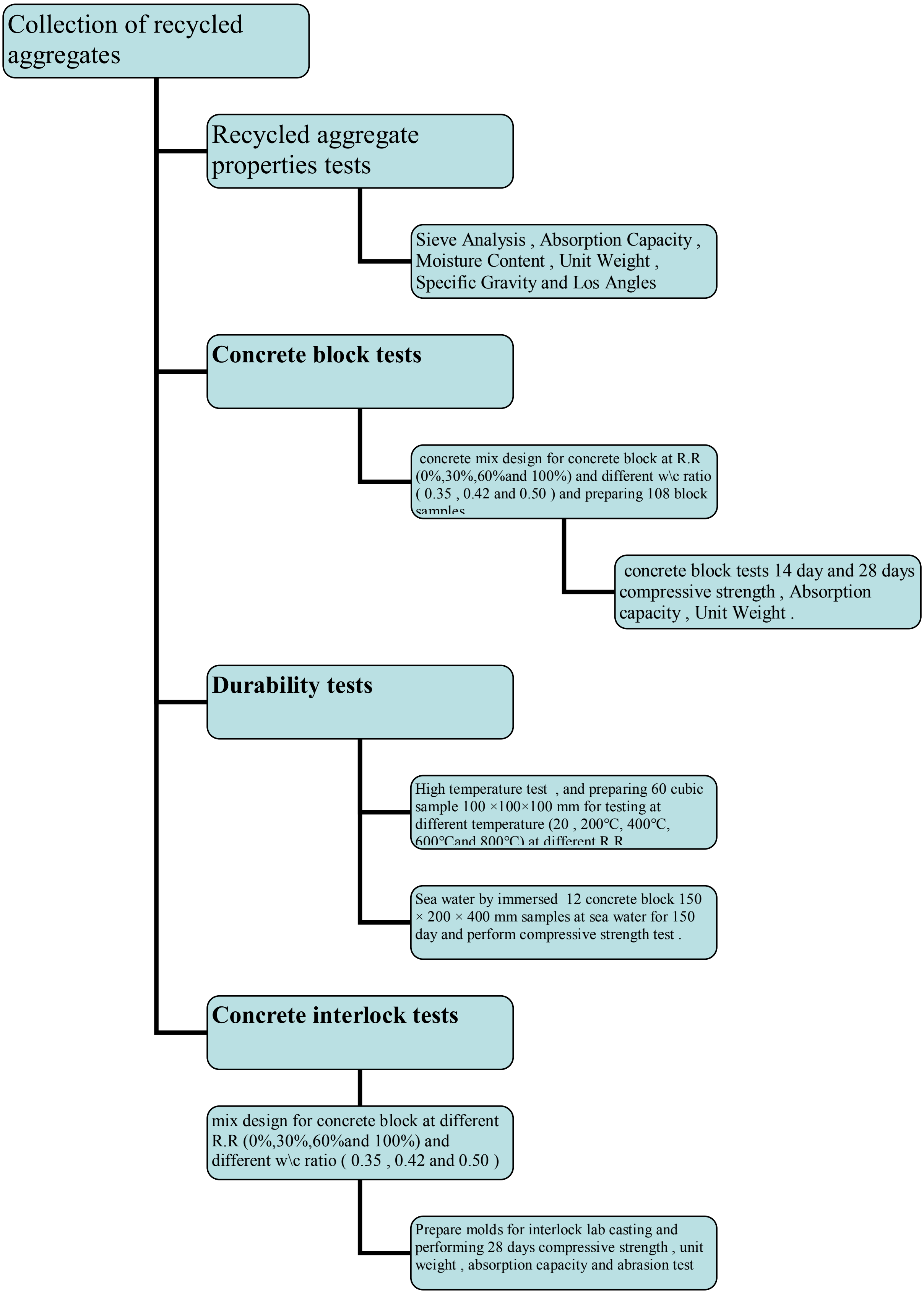

Figure 4.1 Testing program .

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4.2 Material

Concrete is a composite material composed of course granule material (the aggregate or filler) embedded in hared matrix of material (the cement) that fills the space between the aggregate particles and glues them together. Aggregate can be obtained from many different kinds of material, although we mostly make use of the materials of natural common rocks, but recycled aggregate can also be considered as another source of aggregate

4.2.1 Cement

Portland cement type Ì brought from Egypt is used, because of unavailability of Silo Nisher cement in Gaza during performing these tests. Egyptian type can also be classified according to its source . North-Sina type was used for casting specimen. This type is tested at IUG laboratory and was compared with Silo Nisher type as shown below in Figure 4.2

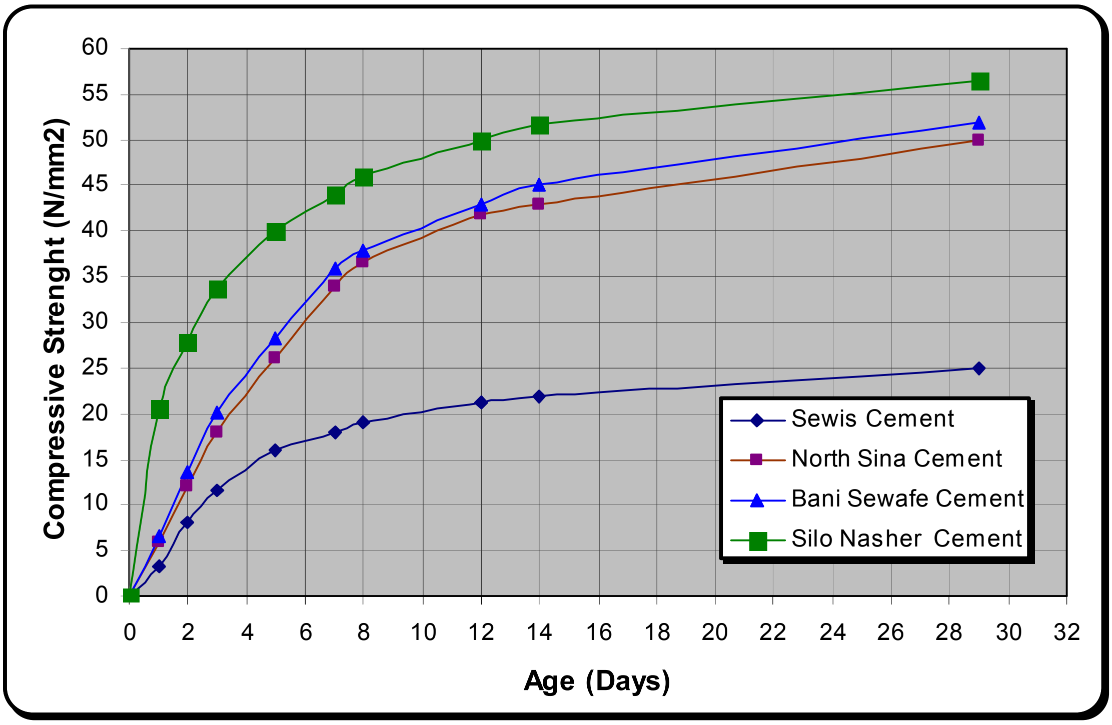

Figure 4.2 Compressive strength of different types of Egyptian cement (IUG laboratory, 2008)

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4.2.2 Water

Tap water, potable without any salts or chemical was used in this study.

4.2.3 Aggregate

The aggregate used in this study can be divided into two types based on its source as natural aggregate and recycled aggregate.

4.2.3.1 Natural Aggregate

Crushed limestone were used as course aggregate with the maximum nominal size 9.5 mm and minimum size 2.63 mm . These are called (*Semsemia*) according to the local market size classification which is suitable for preparing concrete block and concrete interlock.

4.2.3.2 Fine aggregate

The sandy dunes, which are considered as the source of sand, are spread along the Gaza Strip, especially in Rafah, Khan Younis and Bait Lahya . Sand was tested for physical properties

4.2.3.3 Recycled aggregate

Recycled concrete aggregate looks like natural aggregate. However, recycled aggregate has many physical properties that vary from those of natural aggregates. In general, crushed concrete particles are more angular and have a rougher surface texture than natural aggregate. particles with roughly textured, angular shape and elongated particles require more water to produce workable concrete than smooth rounded compact aggregate. The lightweight, porous cement mortar attached to recycled concrete aggregates causes crushed concrete aggregates to have a lower specific gravity and higher water absorption than comparatively sized natural aggregates.

4.2.3.3.1 Recycled aggregate collection

As a result of the closures of border and boundary of the Gaza Strip, the crusher at the site is not ready for use because one of its parts not imported yet. So after site investigation at collection site, there are no ready quantities of recycled aggregate sample to be used for preparing concrete block and interlock samples .And the only available samples have large sizes which exceed 5 inch. And that is not ready to use for preparing concrete block and interlock. In order to overcome this problem, suitable recycled aggregate samples were sieved at dumping site of sieves less than 10 mm.

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4.3 Physical Properties of Aggregate

4.3.1 Sieve analysis

Sieve analysis can commonly be known as "Gradation Test ", and it is essential for all engineering work. Particle size distribution of aggregate has an important effect on concrete production as it determines the paste requirement for workable concrete. Since cement is the most expensive component of concrete, a need to reduce the cost of concrete production, comes up by using the optimum amount of paste during production of concrete, and to satisfy the concrete requirement such as handle, compacted, finishing, strength, density and durability. Concrete can be considered as compacted aggregate particle bonded together by cement paste. The amount of paste depends on the total surface area that must be coated by paste and voids between aggregate that must be filled by paste. This means that the main factor that affects the volume of voids is the particle size distribution of aggregate.

4.3.1.1 Preparing test sample

In order to find the optimum amount of recycled aggregate that must be added to the mix to satisfy standard requirements, many trial samples were prepared using different percentage of recycled aggregate to natural aggregate. This ratio is called replacement ratio (R.R) In this test R.R which was used (0 %, 30%, 60% and 100%) .

4.3.1.2 Course aggregate

Table 4.3 shows the grain size distribution of recycled aggregate. Figure 4.3 shows the grain size distribution of natural aggregate and the grain size distribution of recycled aggregate of (30 %, 60 % and 100%).

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Table 4.3 Grain size distribution for recycled aggregate

Sieve size (mm)	Percentage passing (R.R=0%)	Percentage passing (R.R=30 %)	Percentage passing (R.R=60 %)	Percentage passing (R.R=100 %)	Upper limits	Lower limits
12.5	100	100	100	100	100	100
9.5	97	91.9	86.8	80	100	90
4.75	37	36.31	35.6	34.7	55	20
2.36	5	8.2	11.4	15.6	30	5
1.18	4.4	7.2	9.9	13.6	10	0
0.3	2.4	3.4	4.5	5.9	5	0
F.M	3.54	3.54	3.54	3.50		

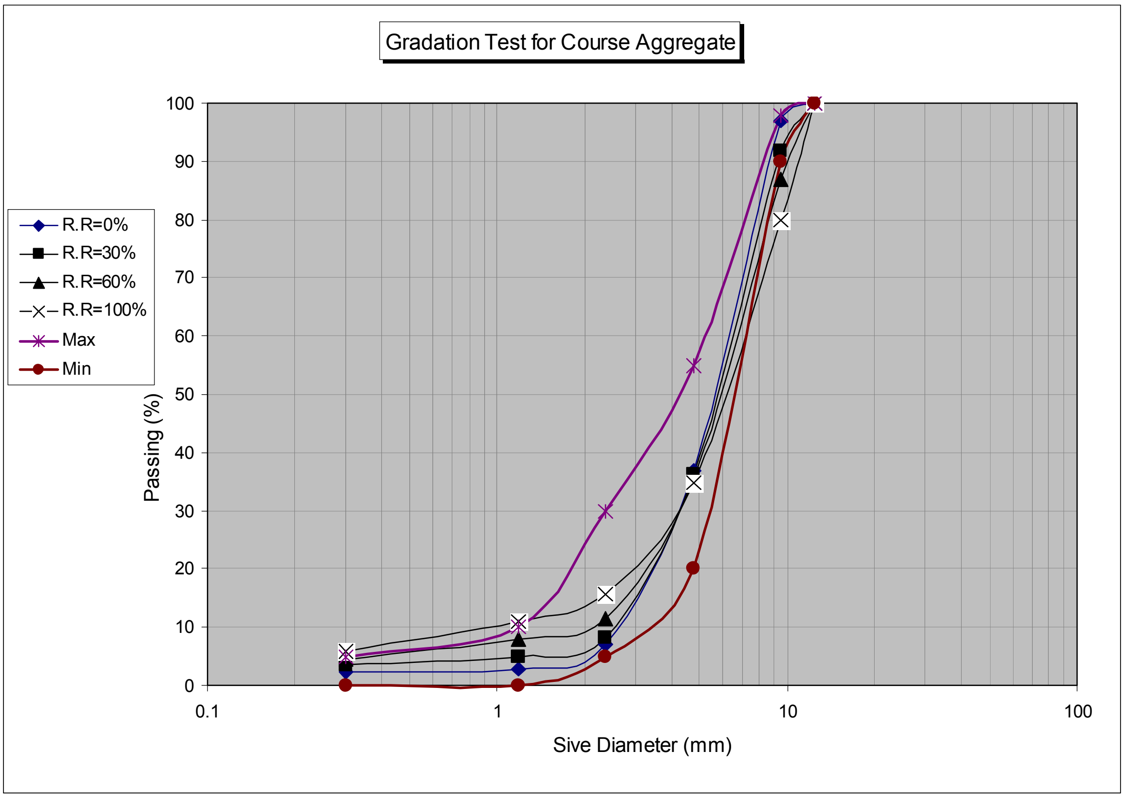

Figure 4.3 Gradation test for mix recycled aggregates and natural aggregate

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4.3.1.3 Fine aggregate

Table 4.4 Grain size distribution of fine aggregate

Sieve size (mm)	Percentage passing (fine aggregate)	Upper limits	Lower limits
4.75	100	100	95
2.36	100	100	80
1.18	98.6	85	60
0.6	94.5	60	30
0.3	63	30	10
0.15	3.3	10	0
0.075	0	5	0
F.M	1.406		

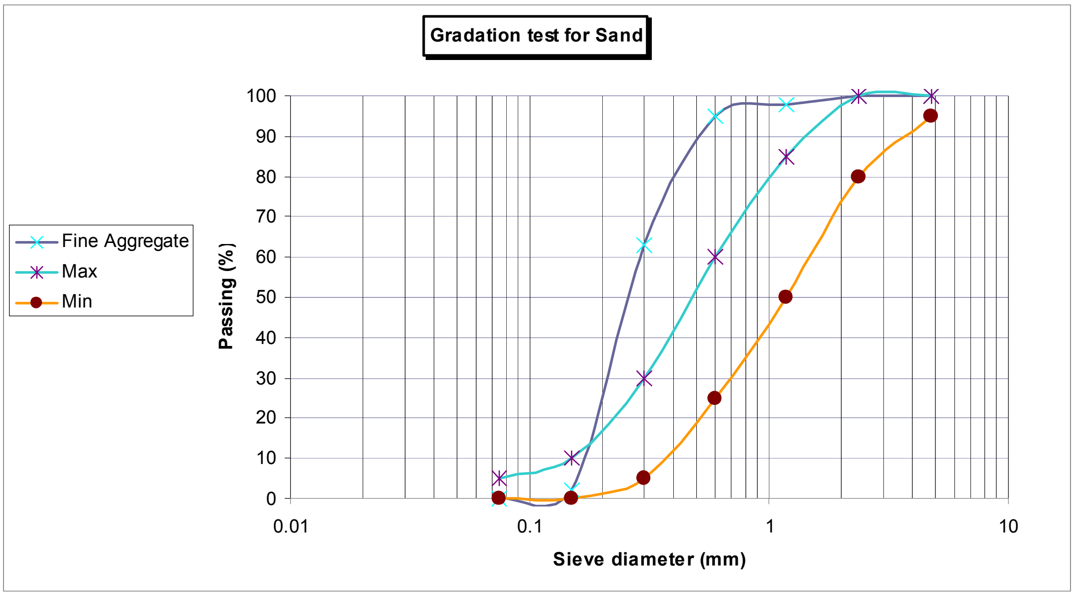

Figure 4.4 Gradation test of fine aggregate

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4.3.1.4 Analysis of Grading tests

Figure 4.3 shows sieve analysis test results for the collected sample performed according to ASTM C 136. In this figure it was noticed that the pure R.A sieve analysis curve is located within the standard ASTM C 33-02a limits, but it exceeds these limits in a small range. and the curves of R.A 30% and 60% content has been modified and located within the standard limits.

4.3.2 Water absorption

It is defined as "the weight of water only present inside the pores of aggregate and expressed as percentage of dry weight", its importance appears when calculating the amount of water that must be added or subtracted to the paste. The absorption capacity is based on the saturated surface, dry condition and oven dry condition. It is necessary to mention that the amount of water in concrete mix has a direct effect on the setting time, compressive strength. This test was performed according to ASTM C127.

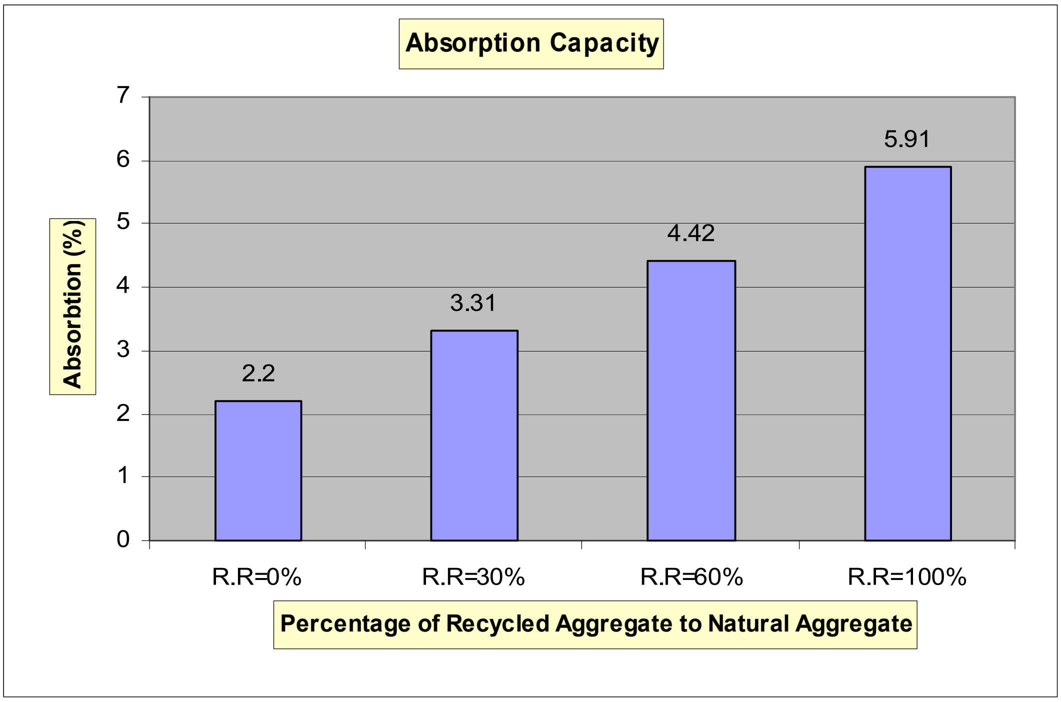

Figure 4.5 Absorption capacities of different samples of recycled aggregate

Figure 4.5 shows that the water absorption ratio "the oven-dried aggregates", was 5.91% for the recycled aggregates, and 2.2 % for the natural aggregate. A high difference was predictable and it is considered as one of recycled aggregates limitations which has effects on the use of concrete or mortar that causes loss in one or several of the following characteristics: mechanical resistance, workability and durability. Pre-

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saturation is a way of minimizing these consequences. In order to overcome high water absorption, 30 min are needed approximately to saturate recycled aggregates. The time-period adopted in the pre-saturation procedure throughout this investigation is also included spreading the aggregates in plastic sheets and leaving them to surface dry for a further 30min before mixing (Devenny and Khalaf,1999)

4.3.3 Unit weight

Unit weight is one of the most important factors required to determine the properties of aggregate. It's importance becomes obvious when calculating the mix design of concrete mix for aggregate. The practical density of aggregate is generally affected by the amount of moisture present, and the geological properties of aggregate. The density of aggregate has an important effect on the unit mass of concrete and the quality of aggregate needed for concrete

In this project, practical density of aggregate was carried out to determine the volume and the weight of aggregate needed for concrete mix. The determination of practical unit weight was carried according to ASTM C29

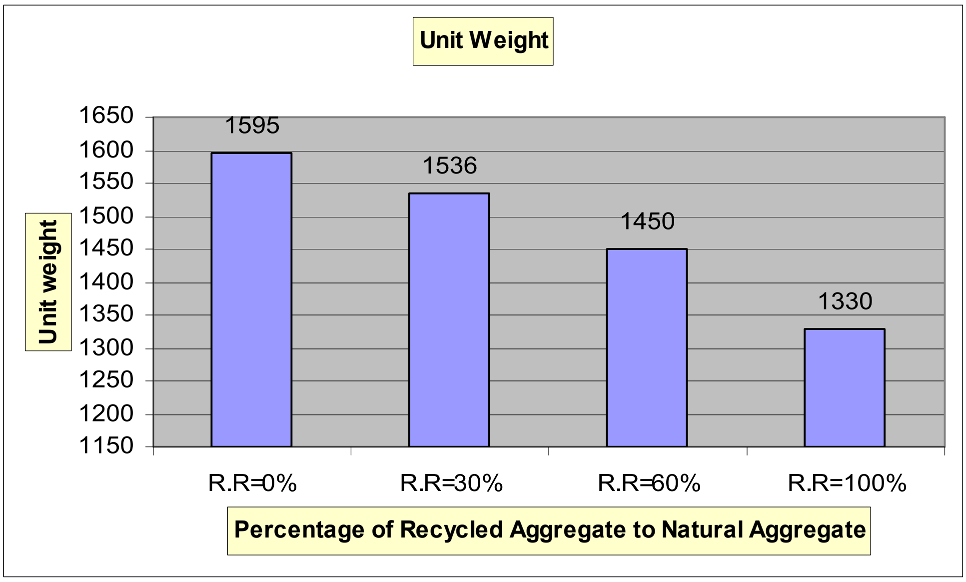

Figure 4.6 Unit weight for different samples of recycled aggregate

The Unit weight of the compacted recycled and natural course aggregates used was determined. For natural aggregates only the unit weight after they were dried in

an oven was measured, but recycled aggregates due to its high water absorption. The air-dried and water saturated densities were also of interest as expected. The unit weight of the recycled aggregates dried in an oven (1330 kg/m3) was smaller than the

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corresponding value for the natural aggregates (1595 kg/m3). Also expected the increasing values of the unit weight of the recycled aggregates from dried in an oven (1330 kg/m3) to be saturated (1408 kg/m3). The latter of which shows the high water absorption to be expected in these aggregates, clearly demonstrating the need to pre-saturate them before mixing.

4.3.4 Moisture Content

The amount of water content in any material has influence on the design and job mix of producing concrete, and the water content depends mainly in the amount of water which exist in course and fine aggregate,and the amount of water to be added to concrete depend on how much water already present.

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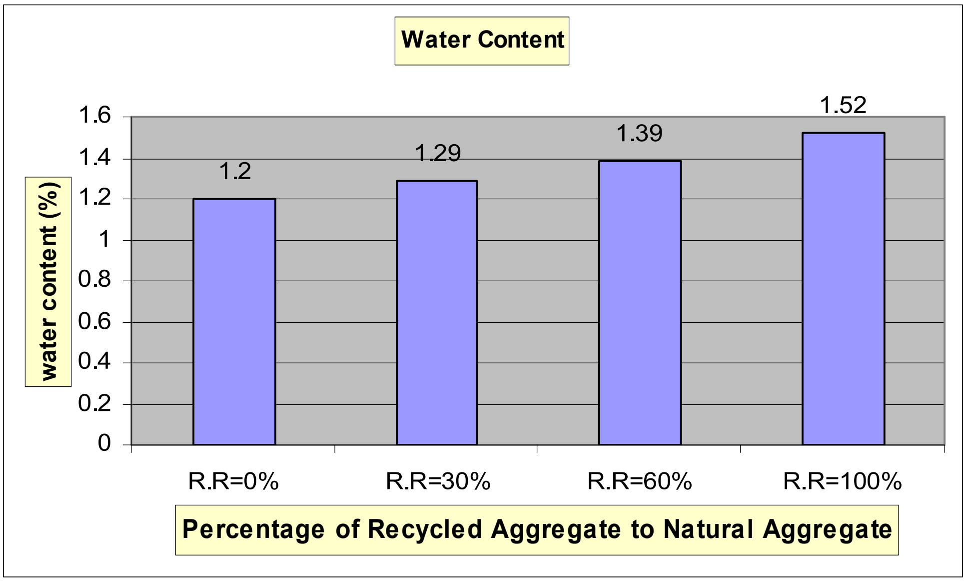

Figure 4.7 Water content for different samples of recycled aggregate

In figure 4.7 it was found that the water content of the recycled aggregate is in the normal range. However, this value would change, based on the weather conditions and season. The water content of pure recycled aggregate was 1.52% and for natural aggregate was 1.2 % and for mix recycled and natural aggregate of 30 % and 60% was 1.29 and 1.39 respectively

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4.3.5 Specific Gravity

Specific gravity is defined as the weight of unit volume of aggregate to the weight of equal volume of water. Specific gravity expresses the density of the solid fraction of the aggregate, and it is used to determine the volume of aggregate in concrete as well as to determine the volume of pores.

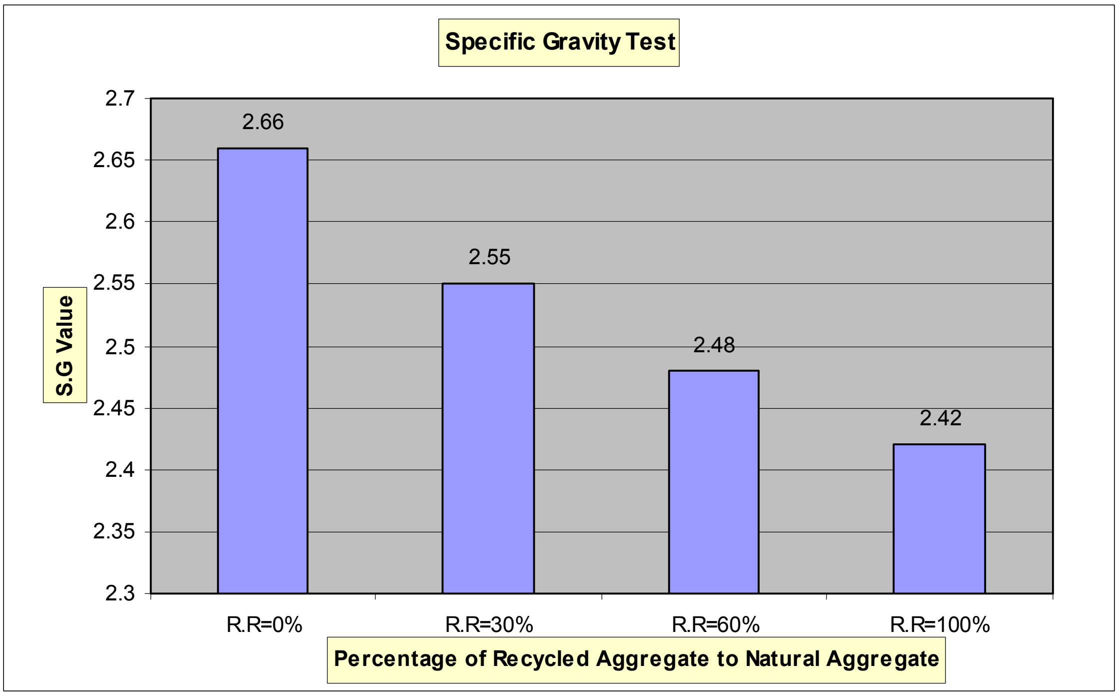

Figure 4.8 Specific gravity test of different samples of recycled aggregate

4.3.6 Resistance to degradation (Los Angeles test)

The Los Angeles test is a measure of degradation of mineral aggregates of standard grading resulting from a combination of actions including abrasion or attrition, impact, and grinding in a rotating steel drum containing a specified number of steel spheres. The L.A. Abrasion test is widely used as an indicator of the relative quality or competence of mineral aggregates.

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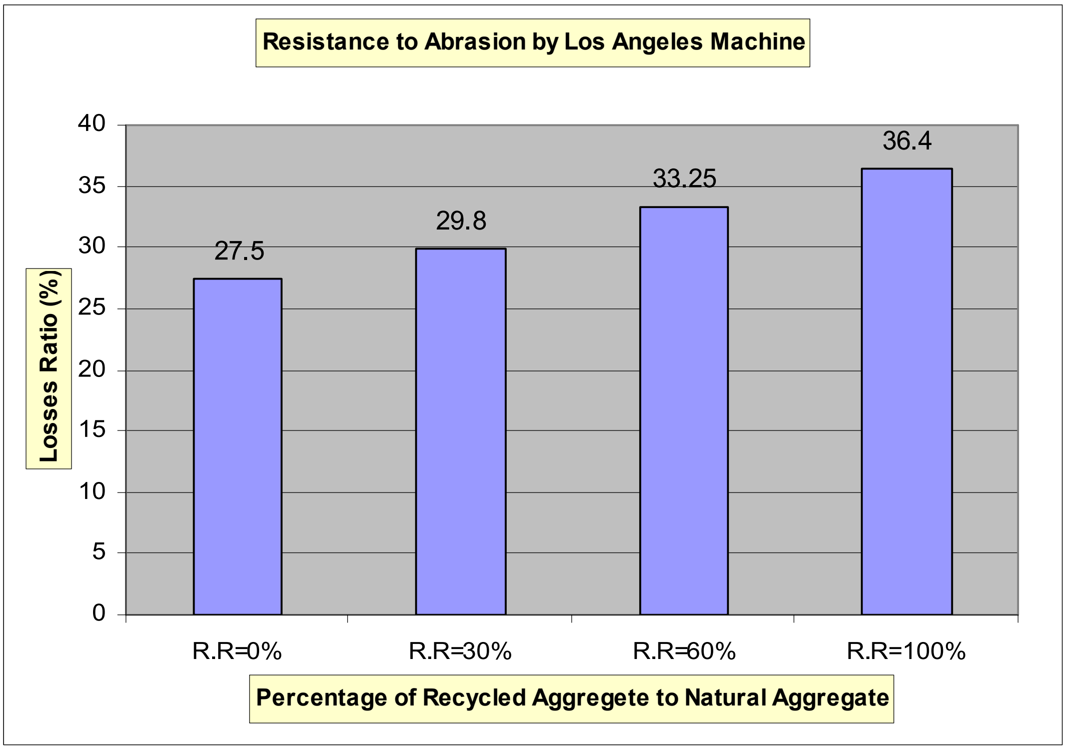

Figure 4.9 Los Angles Test of different samples of recycled aggregate

As shown in figure 4.9 the value of Loss Angles Abrasion of recycled aggregate test doesn't show a relatively high value, the average Los angles value for crushed concrete sample at 500 revelation were ranged from (29.8 to 36.4) for different sample. This indicate that recycled aggregate is adequate for concrete application as specified at ASTM C 33-02 a of aggregate characteristics.

4.4 Concrete block

Concrete block is considered as one of the most important elements in the structure It is used in structure in many cases, like external, internal walls and ribbed slabs.

Concrete block pass through a series of development until it reached its final ordinary shape. In this test, samples of concrete blocks were prepared using recycled and natural aggregate of different R.R. as (0 %, 30%, 60% and 100%)

4.4.1 Advantage of Concrete Block

1. Regular frontages due to their dimensions’ regularity.
2. Both thermal and noise insulation.
3. Good contact between block faces and mortar.
4. Easy haulage due to both small size and weight.
5. Ease in fixing electrical and sanitary works.

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4.4.2 Disadvantage of concrete block

1. High permeability due to high porosity.
2. Good environment for insects and rodents.
3. Easy to crack in the absence of plaster.
4. Formation of algae in the presence of moisture.

4.4.3 Common types of concrete block used in Gaza

In Gaza strip the following block dimension are commonly used

20× 20 × 40
17 × 20 × 40
15 × 20 × 40
12 × 20 × 40
10 · 20 × 40
7 × 20 × 40

4.4.4 Job Mix Design of Concrete Block

For finding job mix quantities to produce concrete block, trial and error approach is more conservative rather than volumetric approach.

Test batches must be run through the machine to be used in production to verify such characteristics as compressive strength, surface texture, absorption and the ability of a freshly molded block to withstand machinery and pallet movement without cracking.

Table 4.5: Mix proportions per unit volume for concrete block

Mix No.	W/C	Cement (Kg/m3)	Natural Aggregate. (Kg/m3)	R.A (Kg/m3)	Sand (Kg/m3)	Water (Kg/m3)
0%	0.35	285.7	1596.2	0	462.6	115.3
	0.42	238.1	1634	0	470	115.8
	0.5	200.0	1662.1	0	478.6	115.9
R.R=30%	0.35	285.7	461.1	1075.9	462.6	130.3
	0.42	238.1	470.0	1096.8	468.5	130.9
	0.5	200.0	480.2	1120.4	478.6	131.6
R.R=60%	0.35	285.7	887.2	591.5	462.6	144.2
	0.42	238.1	904.4	603.0	468.5	145.0
	0.5	200.0	923.9	615.9	478.6	146.0
R.R=100%	0.35	285.7	0	1402.4	462.6	160.9
	0.42	238.1	0	1429.6	468.5	162.1
	0.5	200.0	0	1460.4	478.6	163.4

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4.4.5 Test of concrete blocks

4.4.5.1 Compressive strength

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 this test is easy to make. the strength of the concrete specimens with different percentage of recycled aggregate content can be indicated through the compression test.

The specimens used in this compression test were 150 × 200 × 400 mm concrete hollow block three specimens were used in the compression testing in every batches.

4.4.5.2 Absorption capacity

Absorption capacity used to find the ability of block samples to absorb water. High absorption of block prepared by using recycled aggregate was predictable and clearly points towards the greatest difficulty limitation of the use of recycled aggregates in the production of concrete block without loss in one or several of the following characteristics: mechanical resistance, workability and durability.

4.4.6.3 Block unit weight

Using recycled aggregate in producing block has clear effect on block unit weight .

From test results it was noticed that recycled aggregate reduce block unit weight. This results is good for producing light weight blocks

4.5 Concrete interlock

As a result of Gaza's difficult situation and suffering from closure of border and boundary which prevents importing raw material for industrial, especially cements which influence on all construction factories, according to this situation most of factories were closed and stopped its productions. This situation made it difficult to find interlock block factory to manufacture interlock specimens, so it took a lot of time to find a solution for this obstacles. According to previous studies, a laboratory method for casting interlock samples was used, and this method was applied in this research for specimens productions.

4.5.1 Fabrication of interlock

In this test, steel moulds were manufactured with internal dimension 205 mm long and 100 mm wide and 80 mm height. This mould also has steel thickness and bolts to withstand high pressure which exceed 60 Mpa.

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The concrete mix was compacted at four layer. The first layer was 8 mm of basalt and compacted manually 25 blows using steel hammer. And this done for the second and the third layer. Compaction was applied manually using a hammer, and after the forth layer was poured. A compressive force at rate 600 KN/min was applied for 50 s by mechanically compaction at mix within mould. Excess mortar was then removed with trowel. Finally, compressive force was applied at the same rate for 60 s. Then, the fabrication block in the steel moulds left at room temperature for 24 hours then the interlock were de- molded and cured at water until tests.

4.5.2 Job mix design for interlock concrete block.

This section illustrates job mix design procedure for preparing batch for concrete interlock, and the used procedure was reported at (ACI 211.3R-02). These design procedures were used as a guide for finding the optimum job mix which satisfies mix design consideration, such as adequate durability, strength required and placement.

4.5.3 Job mix procedure :

According to Palestinian local requirement of pre-cast concrete interlock, 50 Mpa is the design compressive strength at 28 days for road application , a nominal maximum-size coarse aggregate 9.5 mm is used (which is locally available). Heavy internal and external dynamic load are available to achieve consolidation, enabling the use of very stiff concrete. Table 4.6 illustrates characteristics of natural and recycled fine and course aggregate

Table 4.6 Characteristics of natural and recycled fine and course aggregate

Characteristics	**Natural aggregate**	**Aggregate of R.R = 30 %**	**Aggregate of R.R = 60 %**	**Aggregate of R.R = 100 %**	**Fine Sand**
Density kg/m3	1595	1536	1450	1330	1630
Moistures content	1.2	1.29	1.39	1.52	0.50
F.M	3.54	3.54	3.54	3.54	1.40
Absorption capacity	2.2	3.31	4.42	5.91	0.35
Specific Gravity	2.66	2.55	2.48	2.42	2.65

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4.5.4 Interlock tests

4.5.4.1 Compressive strength

The specimens used in the compression test were 80 × 100 × 200 mm concrete interlock block three specimens were used in the compression testing in every batches.

4.5.4.2 Absorption capacity

Absorption capacity used to find the ability of interlock samples to absorb water, is has real effect on the following interlock characteristics: mechanical resistance, workability and durability, so its highly recommended to be investigated.

4.5.4.3 Density test

The density of all the interlock samples was determined, and it varied from 2450 kg/m3 for natural aggregate interlock to 2185 kg/m3 for interlock prepared using 100% recycled aggregate. As expected, since the density of recycled aggregate is smaller than the density of the natural aggregates, interlock density decreases as the percentage content of recycled aggregates increases.

4.5.4.4. Abrasion test

Abrasion test is very important test for the concrete interlock. To assess this property, three prismatic specimens, 50 * 70 * 70mm, were made of each mix, by sawing the prismatic specimens used in the flexural tests.

4.6 Durability tests

4.6.1 Marine environment

Concrete is popular material for marine application. It has been used for construction sea defenses, harbors, wharves, jetties and floating structure.

The popularity of concrete for marine construction is due to its economy for large structure. Great improvement in concrete technology has been achieved in the last recent years which increases using concrete in marine structure.

The advance of using cement blended such as slag and microstructure has improved concrete prosperities to be worth in using at marine environment, and the use of various admixture such as supper plasticizer, retarder, air entrainment enhance the properties of fresh and hard concrete, and by the ability of producing high strength concrete, concrete reinforced with fiber which improve durability resistance to cracking, abrasion.

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4.6.2 Chemical composition of sea water

The salinity of sea water is generally about 3.5% of inorganic salts, the principal compounds being sodium chloride and magnesium sulphate . A summary of the ionic concentrations of the various salts in the seas are given in Table 4.7 (Andrew McLeish 1994)

Table 4.7 Concentrations of soluble salts for various seas (Andrew McLeish, 1994)

Ion	Concentration (g per 100 cm³)			
	North Sea	Atlantic Ocean	Baltic Sea	Persian Gulf
Sodium	1.220	1.110	0.219	1.310
Potassium	0.055	0.040	0.007	0.067
Calcium	0.043	0.048	0.005	0.050
Magnesium	0.111	0.121	0.026	0.148
Chloride	1.655	2.000	0.396	2.300
Sulphate	0.222	0.218	0.058	0.400
Total	3.306	3.537	0.711	4.275

4.6.3 Chemical attack

4.6.3.1 Hydrated Portland cement

The main products of hydration of Portland cement are vulnerable to decomposition by the aggressive components of sea water such as CO_2, $MgCl_2$ and $MgSO_4$. These products are formed by hydration of the dicalcium silicate (C_2S) and tricalcium silicate (C_3S) compounds of Portland cement which produce the two crystalline hydrates calcium hydroxide, $Ca(OH)_2$, and tricalcium disilicate hydrate, $3CaO \cdot 2SiO_2 \cdot 3H_2O$ (or$C_3S_2H_3$).Hydration of the tricalcium aluminate (C_3A) compound of ordinary Portland cement, in the presence of gypsum, produces a crystalline monosulphate hydrate, $3CaO \cdot Al2O_3 \cdot CaSO_4 \cdot 18H_2O$, which is responsible for the expansive reaction involving the formation of ettringite when hardened Portland cement comes in contact with sulphate-bearing waters.

The mono sulphate hydrate, of course, is not present in hydration products of sulphate-resisting Portland cements owing to the low C_3A content of less than 3.5% permitted for such cements. Cements containing more than10% by weight of C_3A, such as ordinary Portland cement, are particularly vulnerable to sulphate attack. (Andrew McLeish 1994)

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4.6.3.2 Carbon dioxide

The pH of sea water is normally about 8 and very small amounts of CO_2 dissolved from the atmosphere are present. In the presence of decaying organic matter, however, CO_2 concentrations become high and the sea water becomes acidic with pH values of about 7 or less. In these conditions, carbonation reactions with all the hydrated cement products can result in deterioration of concrete. Carbonation reactions can also occur in concrete exposed to underground waters or flowing and percolating waters with high CO_2 concentrations and low pH. (Andrew McLeish 1994)

4.6.3.3 Magnesium salts

The typical $MgCl_2$ content of sea water is 3200 ppm, which is sufficient to cause deterioration of Portland cement hydrates due to Mg^{2+} ion attack. The calcium hydroxide hydrate reacts as follows to yield dense precipitates of brucite, $Mg(OH)_2$:

$$MgCl_2 + Ca(OH)_2 \longrightarrow \underset{\text{Brucite}}{Mg(OH)_2} + CaCl_2 \quad (4)$$

$CaCl_2$ is leached out of concrete, resulting in material loss and softening. (Andrew McLeish 1994)

4.6.3.4 Sulphate attack

Solutions, such as natural and polluted ground waters and sea water, can cause sulphate attack on concrete. The sulphate ions from sea water react with the hydrates of Portland cement resulting in deterioration of concrete. The following chemical reactions are possible during sulphate attack on cement hydrates in sea water: The high concentration of NaCl in sea water increases the solubility of gypsum and prevents its from rapid crystallization. It also increases the solubility of $Ca(OH)_2$ and $Mg(OH)_2$. The result is leaching of these compounds which makes the concrete weak. The formation of ettringite can cause expansion and cracking, especially in land-based concrete and in laboratory experiment. In marine environments, however, expansion and cracking are normally prevented owing to the solubility of ettringite in sea water.

Ettringite together with gypsum can, therefore, be leached out of concrete. Another difference relative to land-based sulphate attack is that the presence of magnesium sulphate in sea water breaks down the structure of Portland cement paste by attacking the tricalcium disilicate hydrate of the cement. As a result, marine sulphate attacks leaves the concrete soft and brittle. The leaching of compounds and softening of concrete due to sulphate attack are further aggravated by the presence of chlorides in sea

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water. Sulphate attack in the submerged zone of marine concrete is slower than the higher zones where alternate wetting and drying accelerate the deterioration process (Andrew McLeish 1994)

4.6.4 Sea water test

The effect of salt water on the concrete block made of different percentages content of natural and recycled aggregate of (0%, 30%,60% and 100%). The sample were immerged in sea water for 150 days, then compressive strength test were performed on them to investigate the effect of salt in sea water which may react with contamination that exist on recycled aggregate and form new reactive material, which cases deterioration on concrete block .

4.6.5 Temperature test

High temperature test is designed to determine the ability and duration of all the concretes produced in this research, to maintain compressive strength when exposed to high temperatures. In this research, 15 concrete 100*100*100 mm cubes were taken from each mix which produced by using different percentages content of natural and recycled aggregate (0%, 30%,60% and 100%). Compressive strength test were performed for each cubes at different temperatures. Three cubes for each temperature were required from each different mix and tested by compressive strength as well as three cubes that were crushed at room temperature to act as reference sample. The test cubes were placed in a kiln and subjected to designate temperatures of 200, 400, 600 and 800 C for a period of 2h. The cubes were tested hot within 15 min after removal from the kiln for compressive strength. In this experiment 60 cubic concrete samples were tested

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Figure 4.10 High temperature test

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Chapter Five

Test Result and Analysis

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5.1 Concrete blocks tests

5.1.1 Compressive strength test

Compressive strength of block can be defined as the measured maximum resistance of block to axial loading. Compression test is commonly used to find the compressive strength of hardened block specimens. The strength of the block specimens with different content of recycled aggregate has been investigated. This test was performed by using concrete compressive strength machine. According to the Palestinian draft specification, a block compressive strength of 3.5 Mpa is the minimum requirement

5.1.1.1 Compressive strength tests at 14 days

Samples were tested at age of 14 days. Table 5.1 shows the results of testing different blocks with different w/c ratio ranging from 0.35 to 0.5 and different percentage of R.R aggregate (0%, 30%, 60% and 100%).

Figure 5.1 shows that as the percentage of R.R increases the compressive strength decreases. Regression analysis was conducted with 87 % confidence to fit a function to predict block compressive strength. Equation at figure 5.1 can be used to predict the compressive strength at 14 days with w/c ratio of 0.35

Table 5.1 Compressive strength test results at 14 days of concrete block at different R.R and various w/c ratio

(%)R. R of Recycled Aggregate	0	30	60	100
Comp. Strength(Mpa) at w/c = 0.35	4.9	3.9	3.6	3.2
Comp. Strength(Mpa) at w/c = 0.42	5.3	4.5	3.8	3.6
Comp. Strength(Mpa) at w/c = 0.50	4.75	3.7	3.4	3.2

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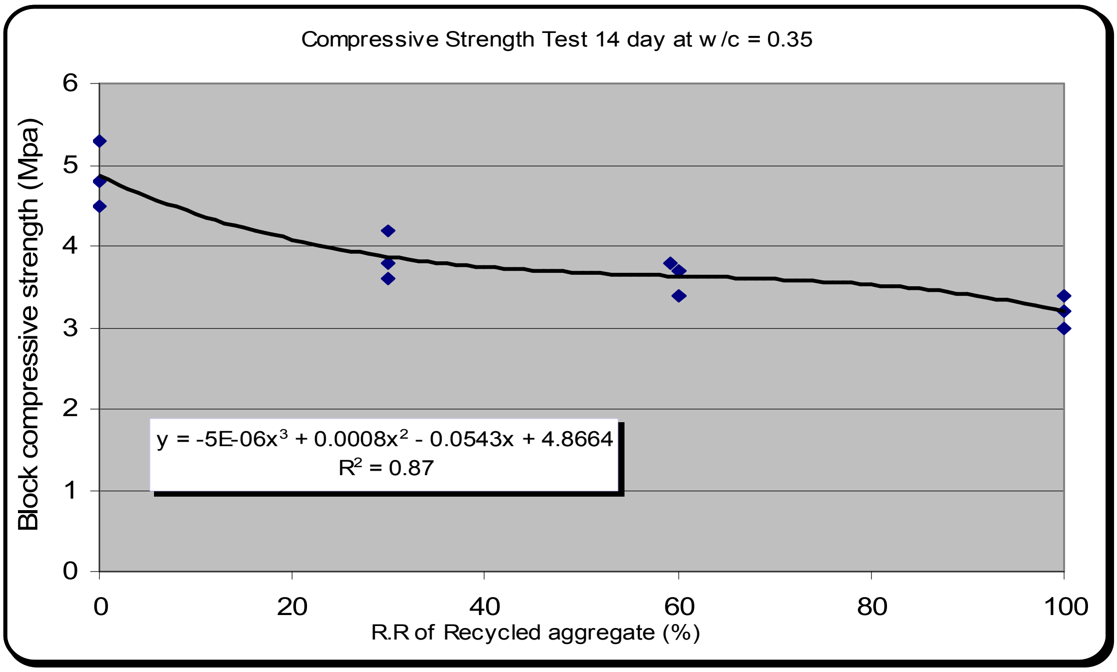

Figure 5.1 Compressive strength test on different R.R of recycled aggregate and w/c = 0.35

Figure 5.2 illustrates 14 days compressive strength test of block sample prepared by using different percentage content of recycled aggregate and w/c ratio 0.42. The confidence interval of regression analysis was 89 %.

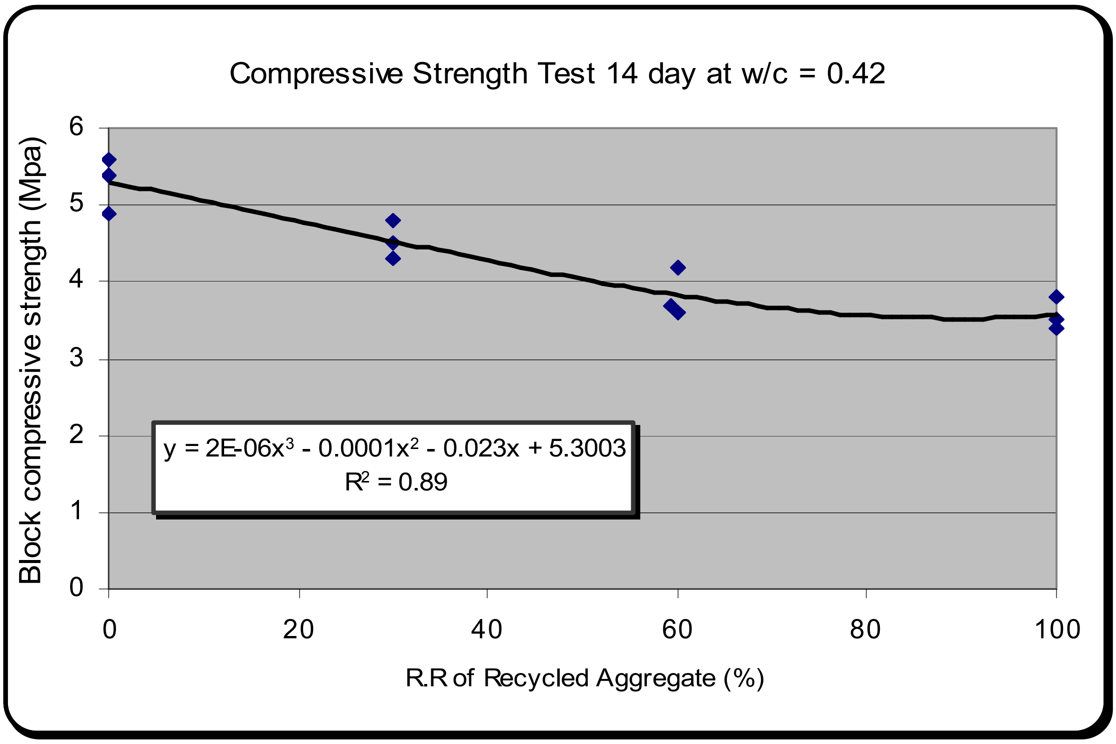

Figure 5.2 Compressive strength test on different R.R of recycled aggregate and w/c = 0.42

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Figure 5.3 indicates that there is a reduction of 14 days block compressive strength test according to increasing in recycled aggregate content in these samples . The confidence of regression analysis which was conducted to these samples was 83 %. These samples were prepared using different percentage of recycled aggregate and w/c ratio 0.50

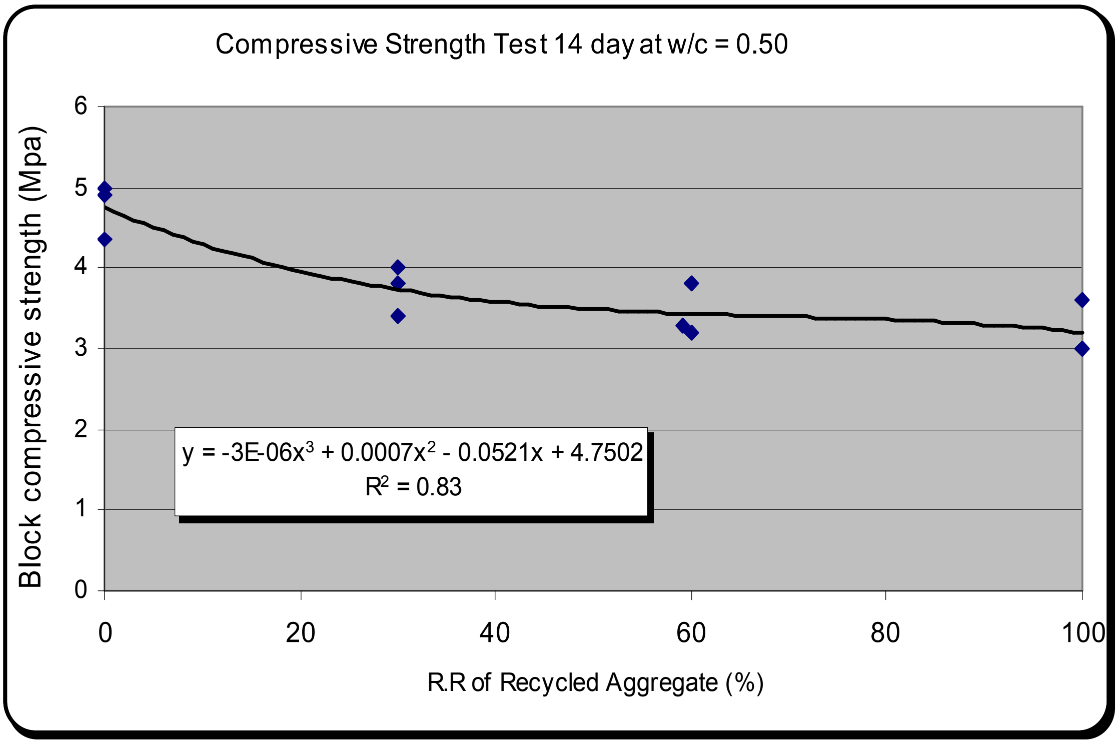

Figure 5.3 Compressive strength test on different R.R of Recycled Aggregate and w/c = 0.50

Figure 5.4 shows 14 days test results of block compressive strength at different percentage content of recycled aggregate (0%, 30%, 60% and 100%) and various w/c ratio (0.35, 0.42 and 0.50). The results demonstrate that there is inverse relationship between compressive strength and recycled aggregate content in these samples .The reduction in compressive strength was 18%, 22% and 34% when using 30%, 60% and 100% respectively of recycled aggregate content.

This results apply to that results collected by Zakaria and Cabrera (1996). They found recycled aggregate block had relatively lower strength than normal aggregate block. They attributed this characteristic to the higher water absorption of recycled aggregate compared with gravel.

Padmini et al (2001). conducted that the strength of block was mostly influenced by the cement content, the aggregate condition (i.e., pre wet or dry before mixing) and the strength of concrete from which the aggregate were derived

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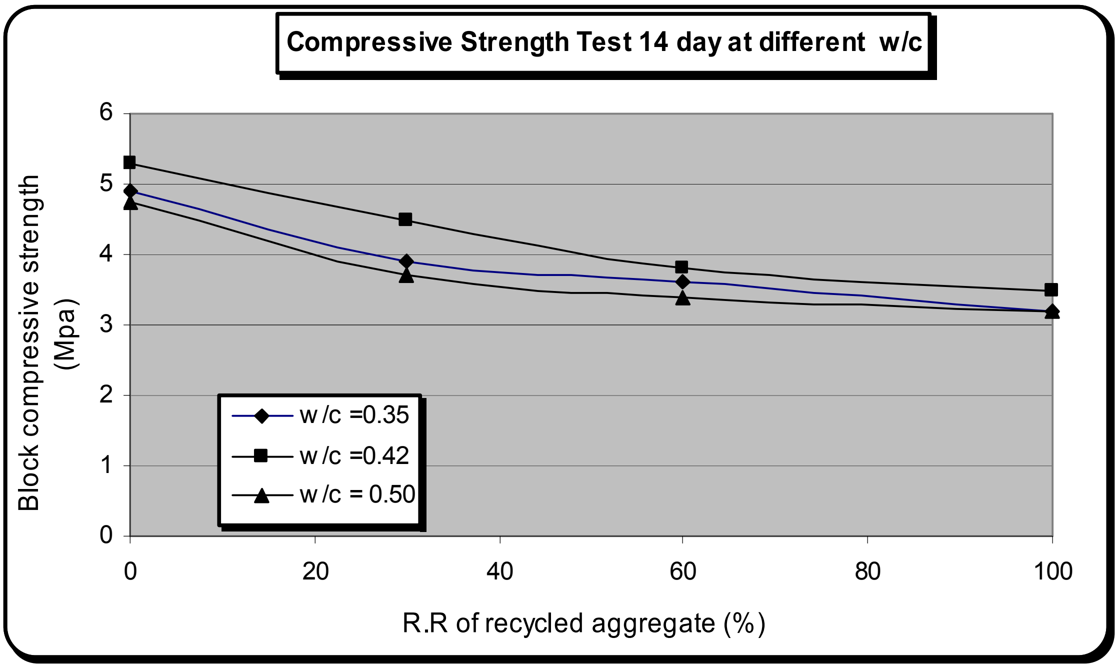

Figure 5.4 Compressive strength test on different R.R of recycled aggregate and various w/c

Figure 5.5 and table 5.2 show the effect of w/c ratio on block compressive strength, It was noticed from this figure that there is proportional relation between block compressive strength and the amount of w/c ratio until 0.42 then the curve begin to decrease. This indicates that 0.42 is the optimum amount of w/c for best block compressive strength at 14 days test results.

The compressive strength of a conventional concrete will increase with the decrease of w/c ratio. Nevertheless, Hansen and Naurd (1983) concluded that, not only the w/c ratio influences on compressive strength of concrete made with 100% of recycled aggregate, but the compressive strength of the recycled aggregate concrete also depends on the strength of the original concrete. The compressive strength of recycled aggregate concrete is strongly controlled by the combination of w/c ratio of the original concrete, when other factors are essentially equal. Therefore, dependence exists with respect to the new-old w/c ratio. When the w/c ratio of the original concrete is equal or lower than of the recycled aggregate concrete, the resistance of the recycled concrete can be equal to or larger than the original one. However, when the w/c ratio of the original concrete is high ,the original concrete strength will determine the new concrete strength.

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In accordance with Rasheeduzzafar and Khan (1984) the compression strength of concrete made with 100% of recycled aggregates and with a w/c ratio lower than 0.4 could not increase due to the strength of original concrete . In Concrete made with 100% of recycled aggregates, the compressive strength depends on the recycled aggregates strength more than on the cement paste strength.

Table 5.2 Compressive strength test on 14 days of concrete block at different R.R and Various w/c ratio

Ratio w/c	0.35	0.42	0.5
Comp. Strength(Mpa) at R.R = 0%	4.9	5.3	4.75
Comp. Strength(Mpa) at R.R = 30%	3.9	4.5	3.7
Comp. Strength(Mpa) at R.R =60%	3.62	3.8	3.4
Comp. Strength(Mpa) at R.R = 100%	3.2	3.5	3.2

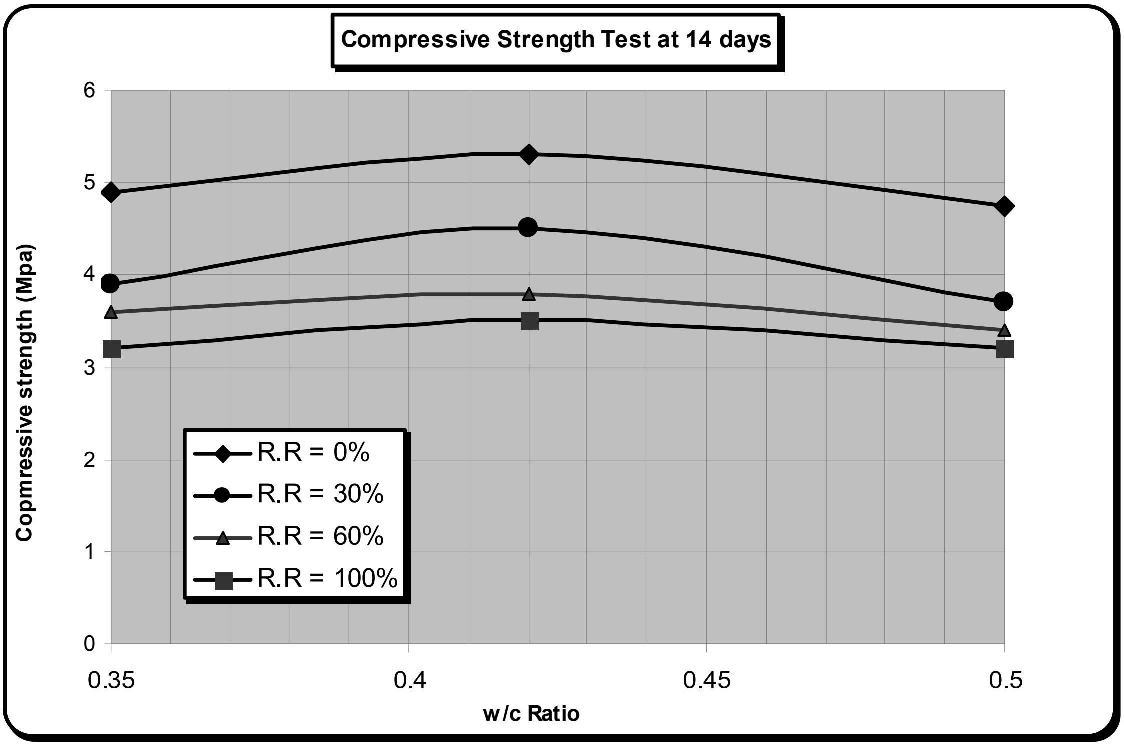

Figure 5.5 Relation between compressive strength and w\ c Ratio at 14 days test

5.1.1.2 Compressive Strength Tests at 28 days

Figure 5.6 shows 28 day block compressive strength test , these block samples were prepared using different percentage of recycled aggregate content (0%, 30%, 60% and 100%) and w\c ratio 0.35 . Curve regression was conducted with 88% confidence to predict block compressive strength progress according to increasing recycled aggregate content.

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Table 5.3 Block compressive strength test results at 28 days of concrete block with different R.R and various w/c ratio

R. R of Recycled Aggregate (%)	**0**	**30**	**60**	**100**
Comp. Strength(Mpa) at w/c = 0.35	5.6	4.6	4.2	3.7
Comp. Strength(Mpa) at w/c = 0.42	6.5	5.5	4.5	4.3
Comp. Strength(Mpa) at w/c = 0.50	5.3	4.3	3.9	3.5

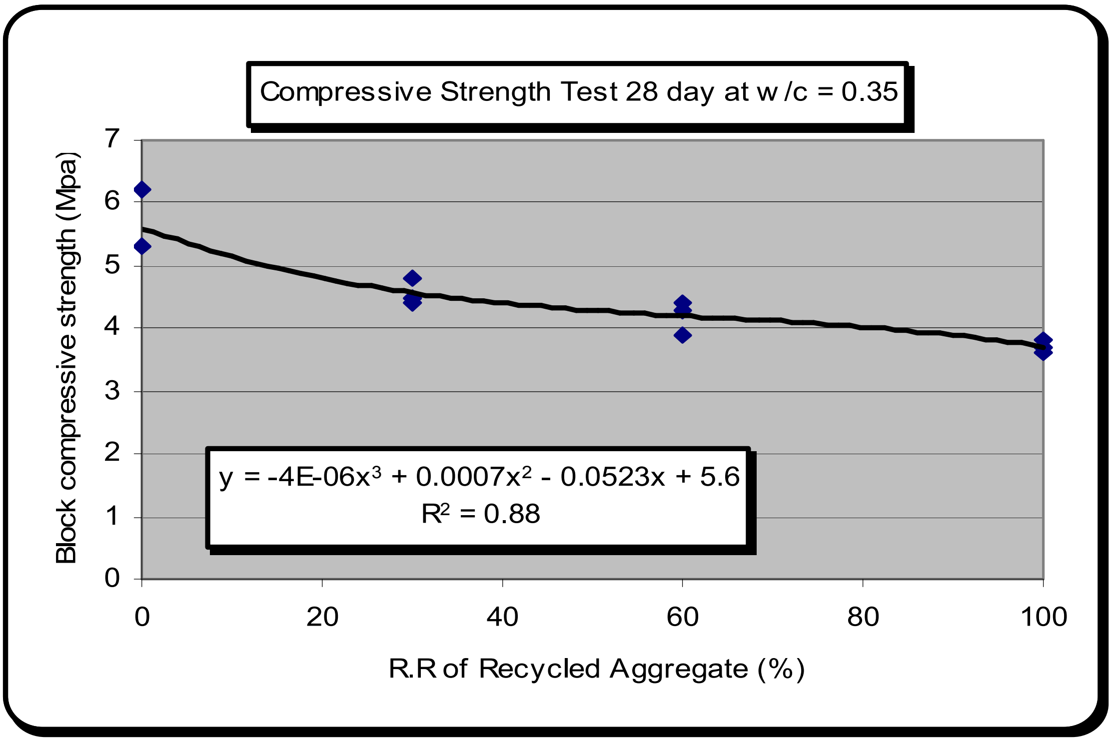

Figure 5.6 Compressive strength test on different R.R of Recycled Aggregate and w/c = 0.35

Figure 5.7 illustrates 28 days compressive strength test results of block sample prepared using w/c ratio 0.42 and different recycled aggregate content.

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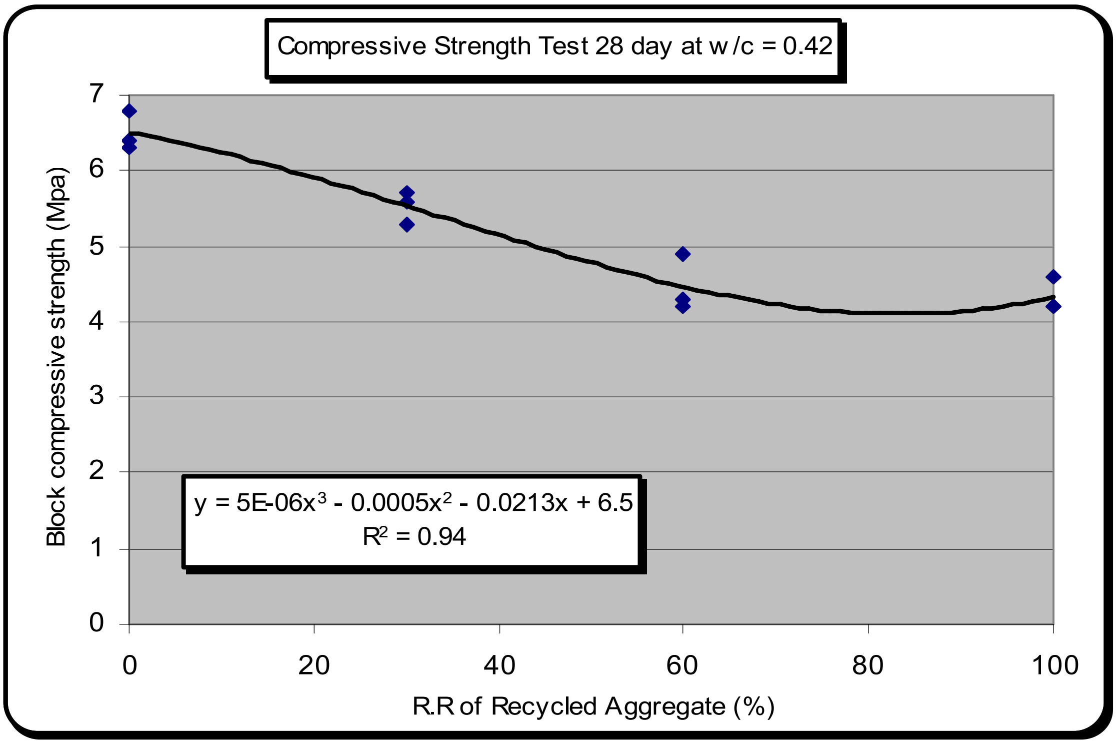

Figure 5.7 Compressive strength test on different R.R of recycled aggregate and w/c = 0.42

Figure 5.8 shows 28 days compressive strength test results of block sample prepared using 0.50 w/c ratio with different recycled aggregate content .The curve regression of test results have 93 % confidence.

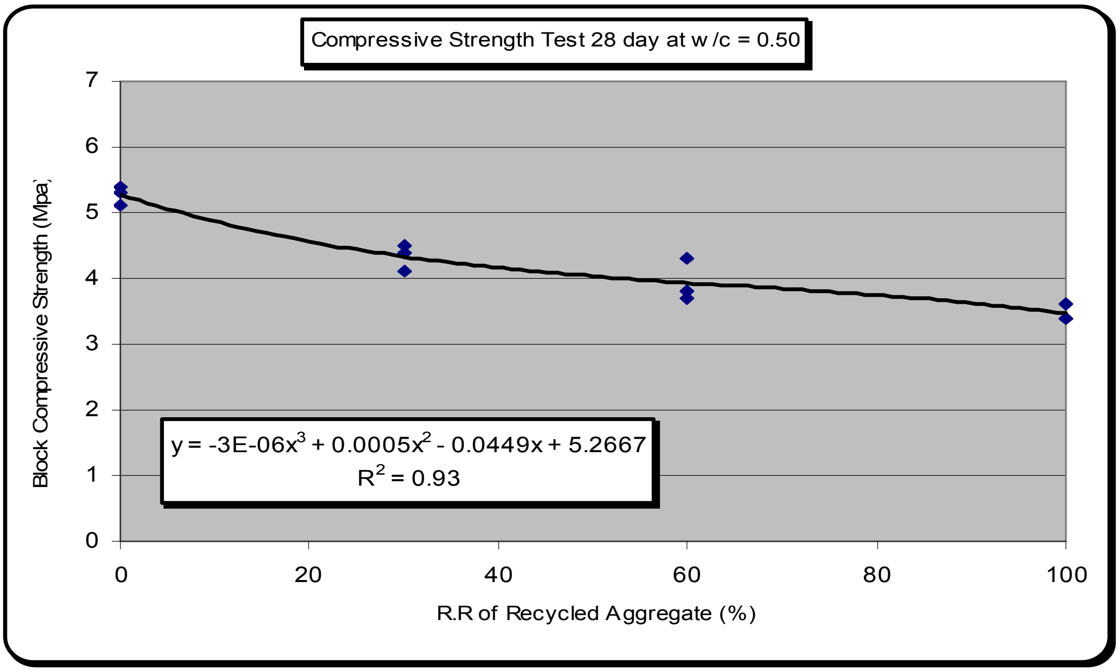

Figure 5.8 Compressive strength test on different R.R of recycled aggregate and w/c = 0.5

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Figure 5.9 shows all experimental data at 28 days compressive strength test. By making best fit interpolation curve for this data, it was noticed that the reduction in compressive strength was 15%, 28% and 32% when using 30%, 60% and 100% respectively of recycled aggregate.

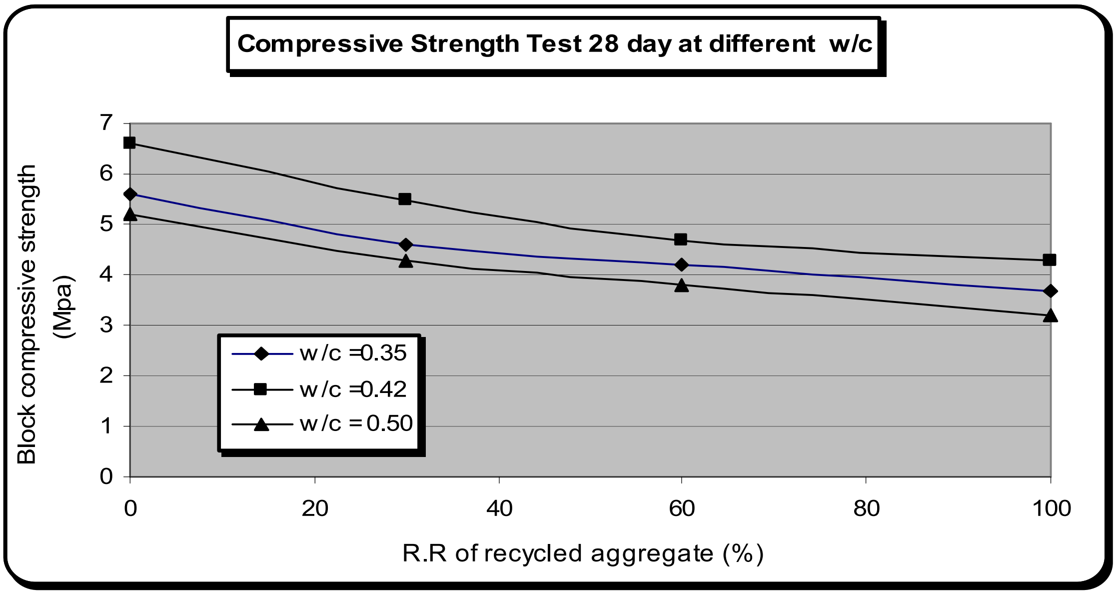

Figure 5.9 Compressive strength test on different R.R of recycled aggregate and various w/c

5.1.1.3 Compressive strength test on different w/c Ratio at 28 days

Figure 5.10 shows the effect of w/c ratio on block compressive strength, it was noticed from this figure that the compressive strength increase according to increasing the amount of w/c ratio until 0.42 then the curve begin to decrease. This result indicates that 0.42 is the optimum amount of w/c ratio which produces best block compressive strength at 28 days test.

Table 5.4 compressive strength test on 28 days of concrete block at different R.R and different w/c ratio

Ratio w/c	0.35	0.42	0.5
Comp. Strength(Mpa) at R.R = 0%	5.6	6.6	5.2
Comp. Strength(Mpa) at R.R = 30%	4.6	5.5	4.3
Comp. Strength(Mpa) at R.R =60%	4.2	4.7	3.8
Comp. Strength(Mpa) at R.R = 100%	3.7	4.3	3.4

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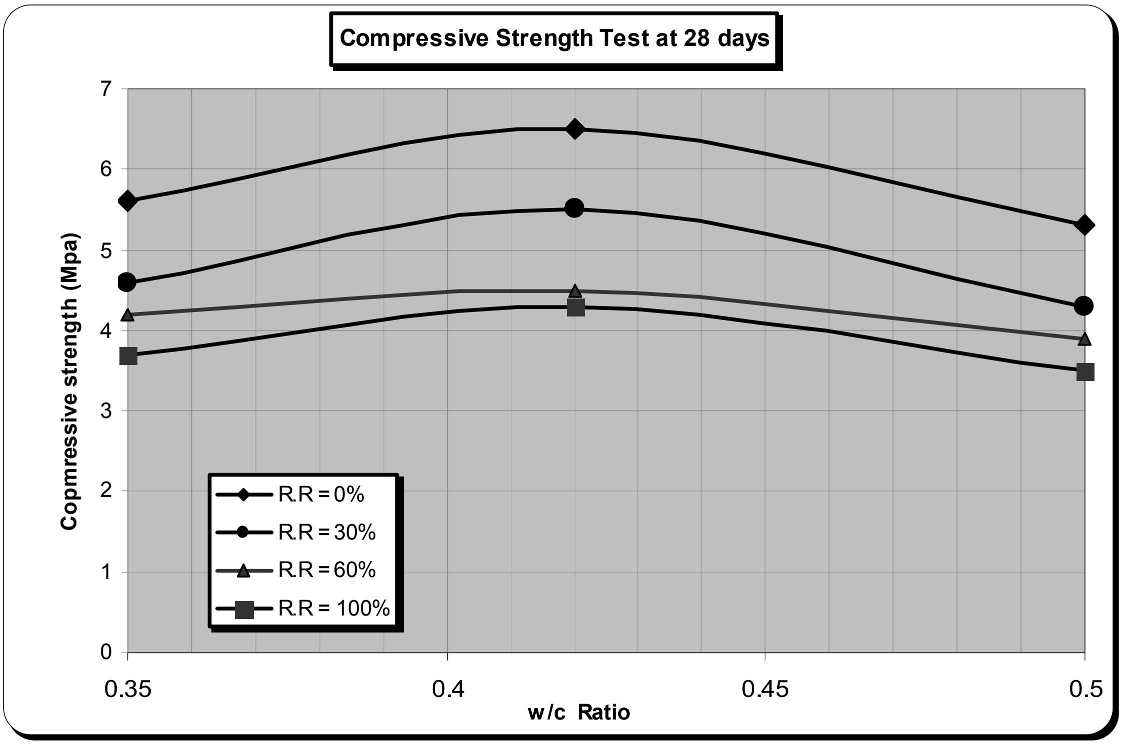

Figure 5.10 Relation between compressive strength and w/c Ratio at 28 days test

Although there is a reduction in block compressive strength when using more amount of recycled aggregate in producing block samples, the block of 100% recycled aggregate content can be produced and apply local requirements, 3.9 MPa Compressive strength can be produced using 100 % of recycled aggregate at 28 days test.

The results are higher than the minimum block compressive strength required according to local requirement, which is 3.5 MPa. The previous results demonstrate that the optimum amount of w/c ratio which can be used for producing concrete block is 0.42 which gives higher compressive strength results.

5.1.2 Absorption Capacity Test

Figure 5.11 shows the absorption capacity for concrete block samples which were prepared by using different percentage of recycled aggregate and w/c ratio 0.35.

Table 5.5 Absorption capacity test results of concrete block

R.R of Recycled Aggregate	0	30	60	100
absorption capacity at w/c Ratio = 0.35	3.97	6.28	7.08	7.8
absorption capacity at w/c Ratio = 0.42	4.77	6.74	7.1	9.36
absorption capacity at w/c Ratio = 0. 5	4.7	6.36	6.5	7.3

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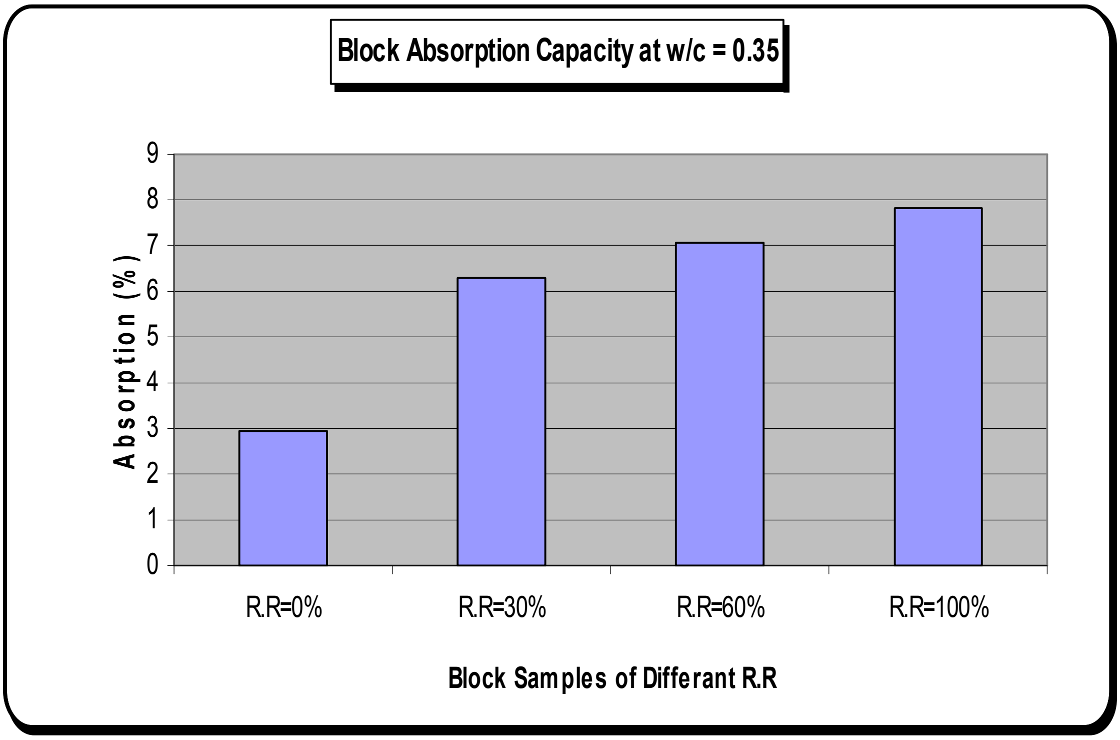

Figure 5.11 Absorption Capacity test on different R.R of recycled aggregate and w/c = 0.35

Figure 5.12 shows absorption capacity test of block samples prepared using w/c ratio 0.42 and different percentage content of recycled aggregate

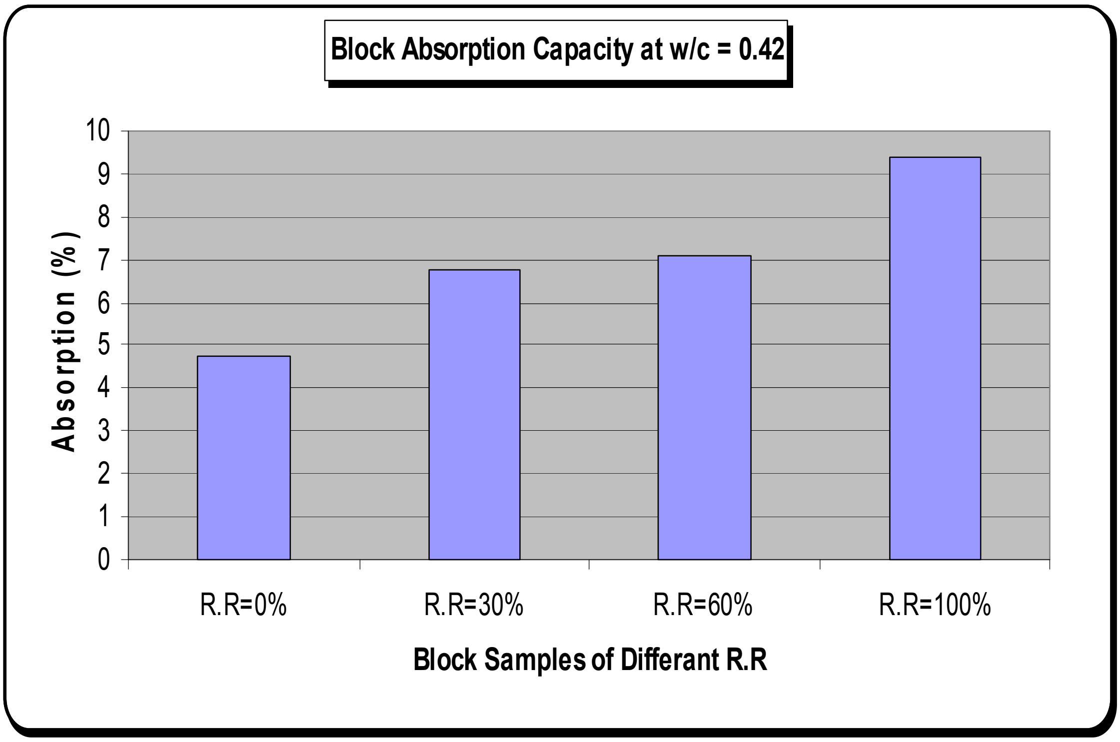

Figure 5.12 Absorption Capacity test on different R.R of recycled aggregate and w/c = 0.42

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Figure 5.13 shows the effect of recycled aggregate on the absorption capacity of the block . These block samples were prepared by using 0.50 w/c ratio.

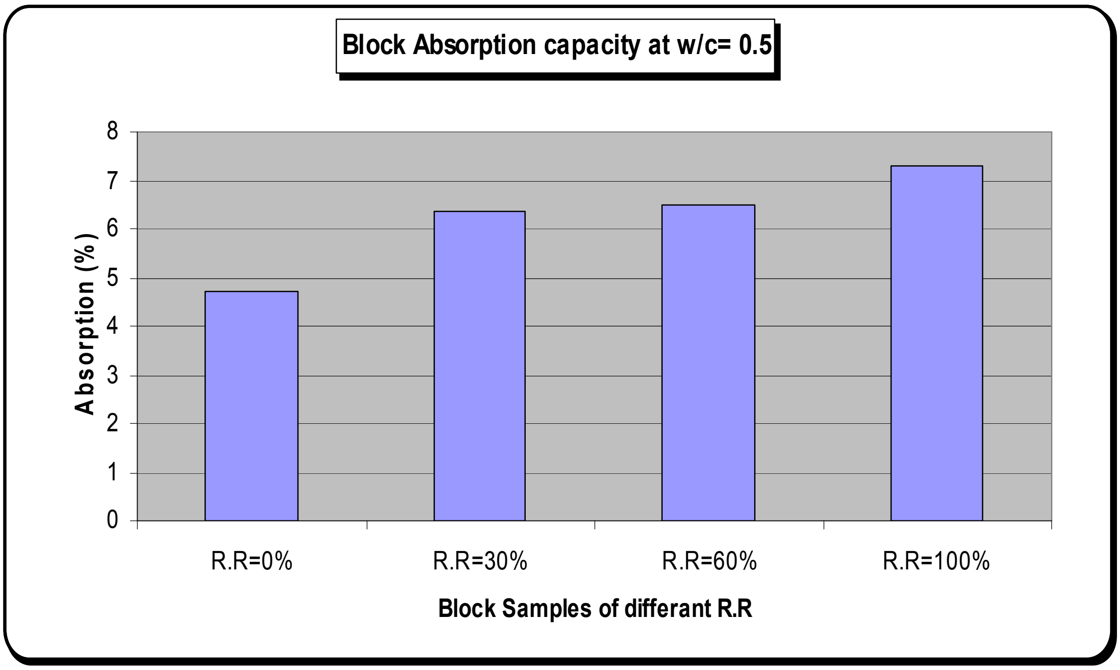

Figure 5.13 Absorption capacity test on different R.R of recycled aggregate and at w/c = 0.50

The best fit curve for the relationship between percentage of recycled aggregate content and block absorption capacity was illustrated at figure 5.14.

Figure 5.14 demonstrates that there is a proportional relation between absorption capacity and percentages content of recycled aggregate in block samples. Absorption capacity increased by 66%, 72% and 110% when using 30%, 60% and 100% respectively of recycled aggregate content.

This results due to water absorption of recycled aggregate are higher than water absorption of natural aggregate. Whereas aggregate which forms about 70% of total block weight, so its properties have influence on block properties.

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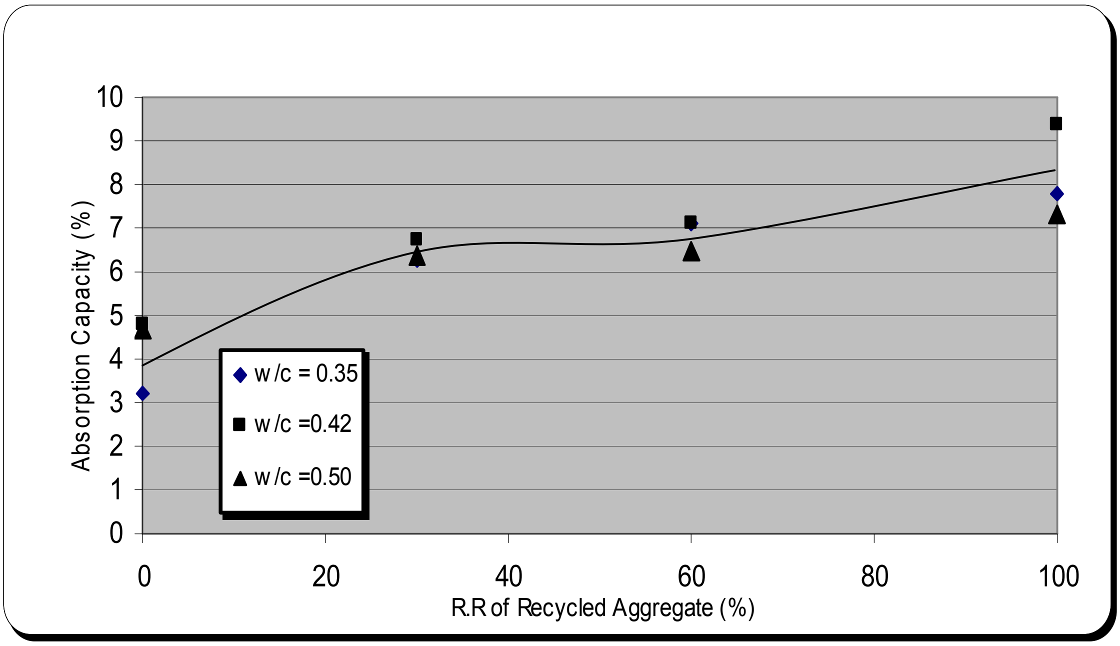

Figure 5.14 Absorption capacity test on different R.R of recycled aggregate at various w/c ratio

5.1.3 Unit weight

Figure 5.15 shows the relationship between block unit weight and percentage content of recycled aggregate at w/c ratio 0.35 .

From this figure, it was noticed that there is a reduction of block unit weight due to the increasing percentages of recycled aggregate content.

This results reasoned by the unit weight of blocks influenced by the unit weight of aggregate. whereas recycled aggregate unit weight is lower than natural aggregate unit weight, so recycled aggregate block unit weight is lower than natural aggregate block unit weight.

Table 5.6 Unit weight of concrete block

R.R of Recycled Aggregate	**0**	**30**	**60**	**100**
unit weight at w/c Ratio = 0.35	1279	1207	1080	1030
unit weight at w/c Ratio = 0.42	1265	1195	1060	1016
unit weight at w/c Ratio = 0. 5	1257	1170	1050	1007

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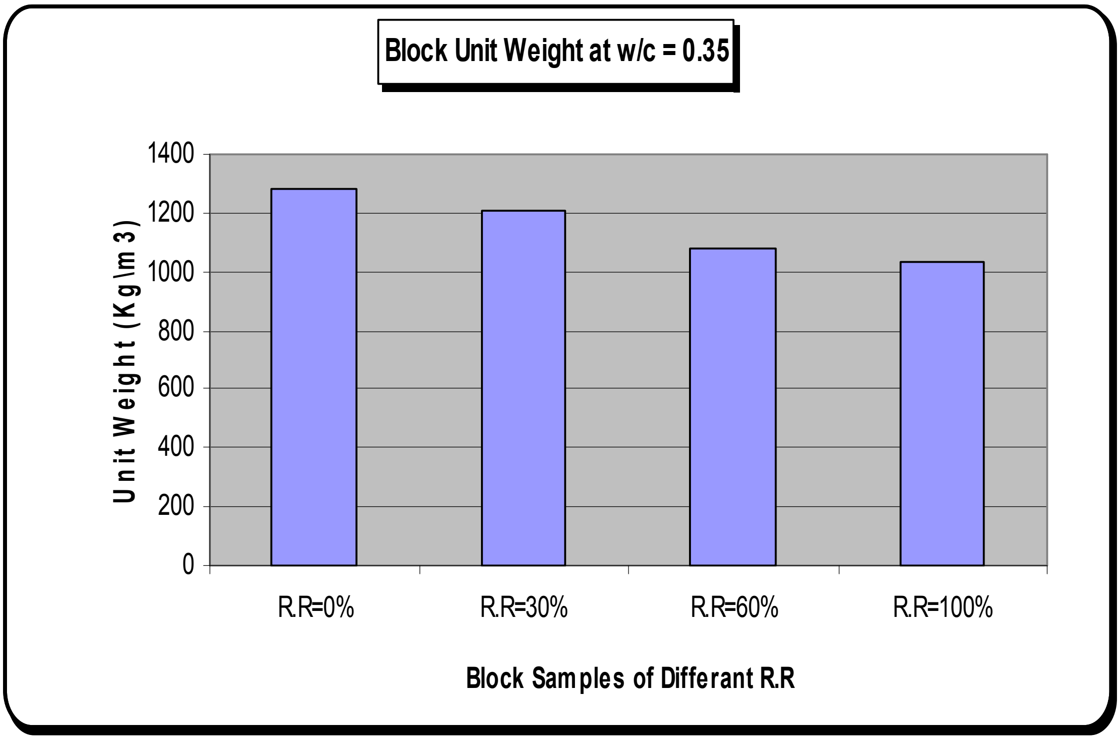

Figure 5.15 Unit weight test on different R.R of recycled aggregate and w/c = 0.35

Figure 5.16 illustrates the effect of recycled aggregate content on the block unit weight. These samples prepared using different content of recycled aggregate and 0.42 w/c ratio.

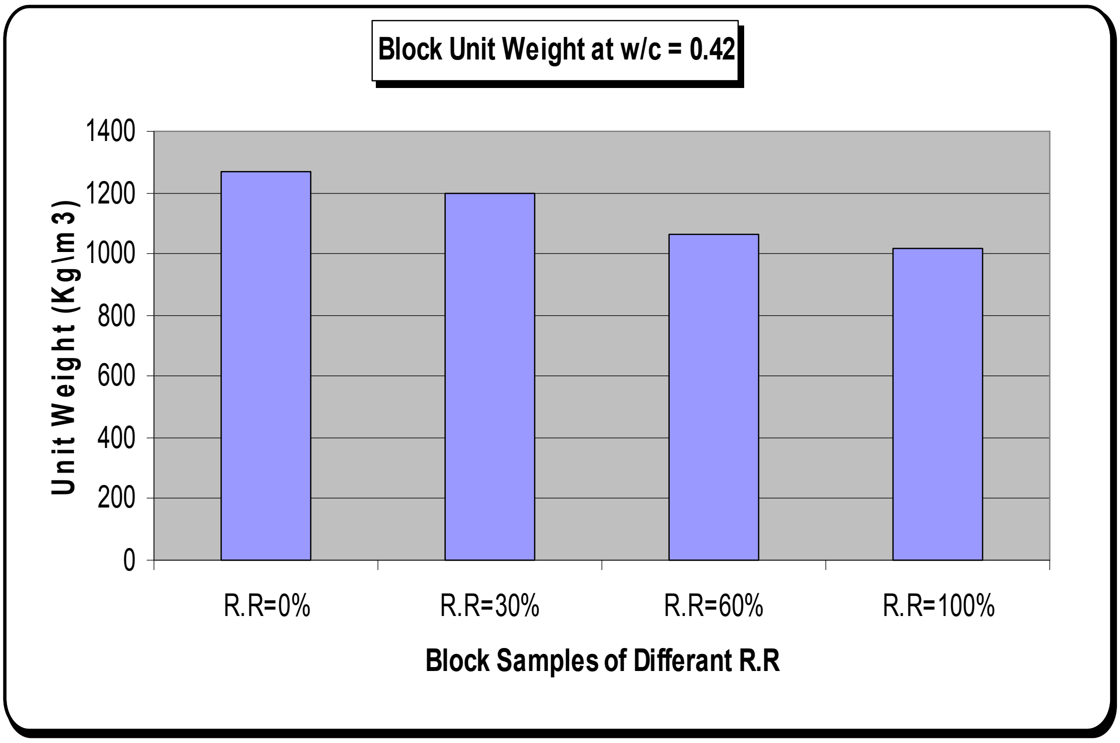

Figure 5.16 Unit weight test on different R.R of Recycled Aggregate and w/c = 0.42

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Figure 5.17 shows the unit weigh of blocks prepared using 0.50 w/c ratio and different percentage content of recycled aggregate.

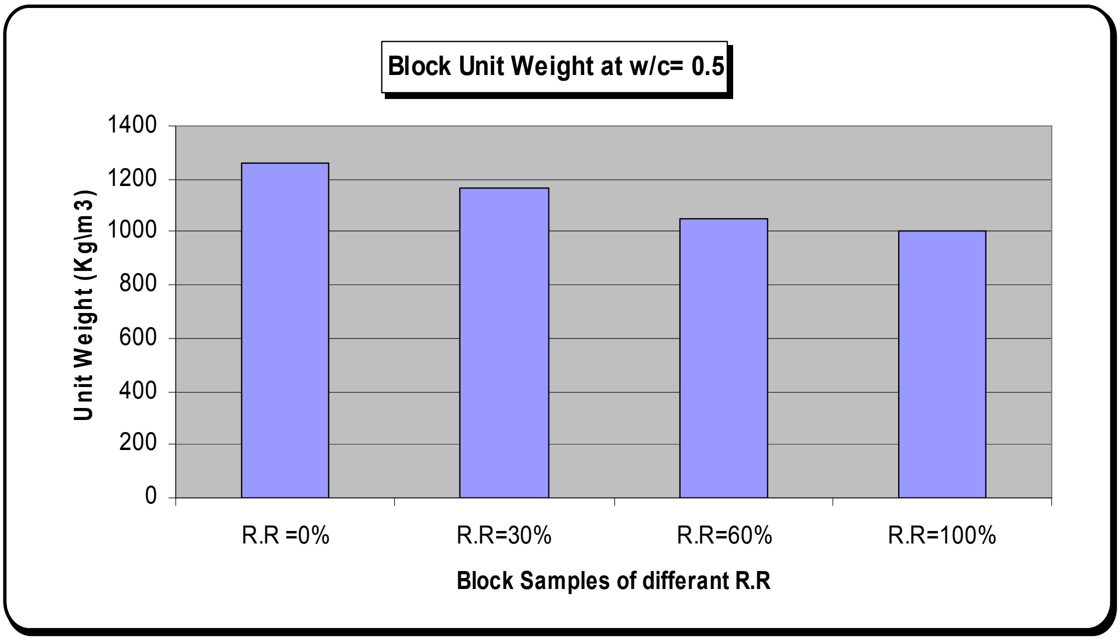

Figure 5.17 Unit weight test on different R.R of recycled aggregate and w/c = 0.50

Figure 5.18 demonstrates that there is inverse relation between block unit weigh and recycled aggregate content in block .

Curve regression was conducted to fit a function for predicting block unit weight behavior . From this figure it was noticed that the reduction on unit weight was 6%, 16% and 19.5% when using recycled aggregate 30%, 60%and 100% respectively.

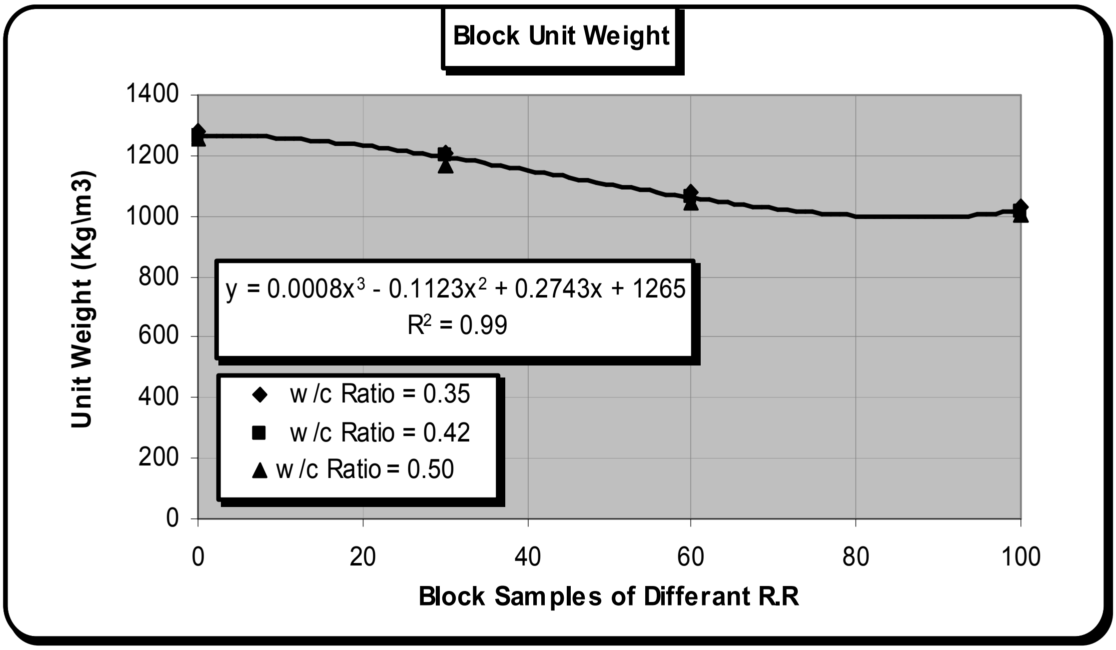

Figure 5.18 Unit weigh test on different R.R of recycled aggregate and various w/c ratio

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5.2 Interlock test results

In order to evaluate the adequacy of using recycled aggregate in producing interlock , 12 interlock samples with 80*100*200 mm dimension prepared. Many standard tests were preformed: Density test, water absorption, 28 days compressive strength and abrasion resistance.

5.2.1 Density test

It is obvious from figure 5.19 that there is a reduction in interlock density according to increasing recycled aggregate content . This figure shows that the reduction was 3%, 6% and 11%when using recycled aggregate 30%, 60%and 100% respectively.

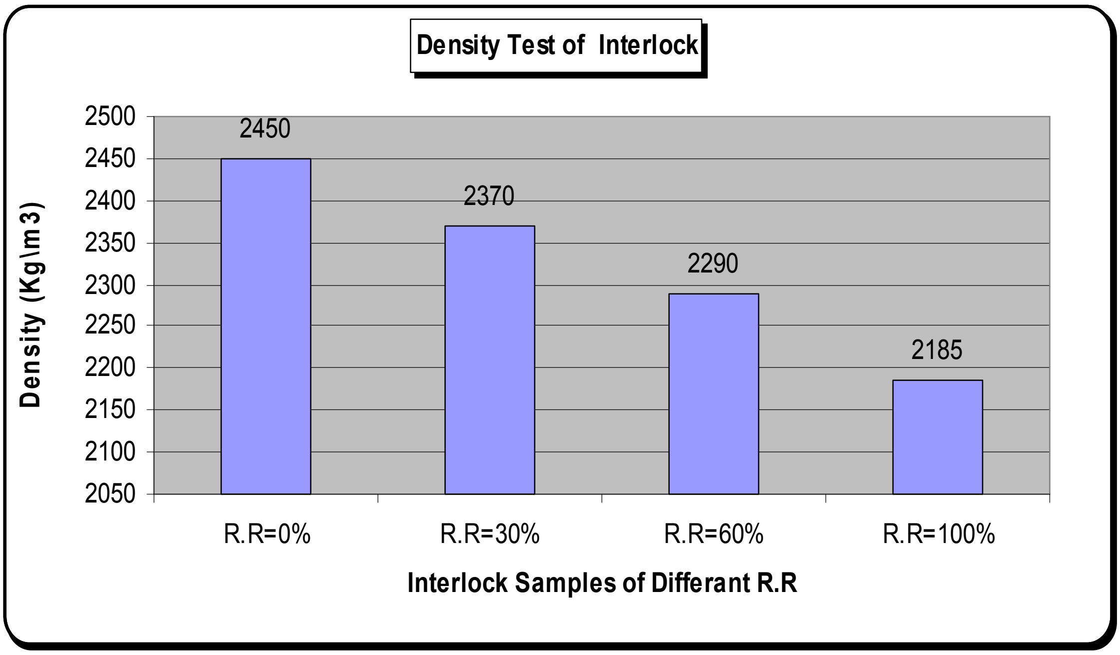

Figure 5.19 Density test for Interlock at different R.R

5.2.2 Absorption Capacity

As seem in figure 3.20 interlock absorption capacity increases according to increasing recycled aggregate content. It was noticed from this figure that the reduction was 18%, 25% and 27% when using interlock with recycled aggregate 30%, 60%and 100% respectively.

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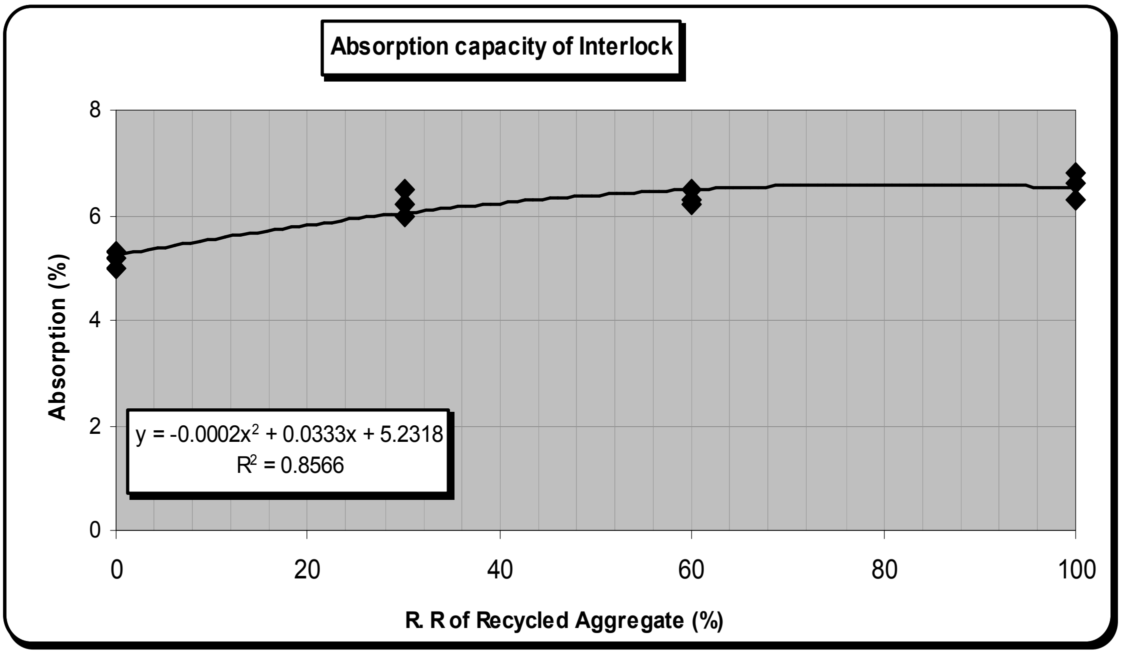

Figure 5.20 Density test for interlock at different R.R

5.2.3 Compressive strength for interlock at 28 days

Figure 5.21 illustrates the compressive strength results of interlock samples at 28 days . the samples were prepared using different recycled aggregate content (0%, 30%, 60% and 100%) at 0.42 w/c ratio. The results demonstrated that there is a reduction in interlock compressive strength according to increasing of recycled aggregate content. This reduction was 7%, 12%, and 25 at recycled aggregate content 30%, 60% and 100%.

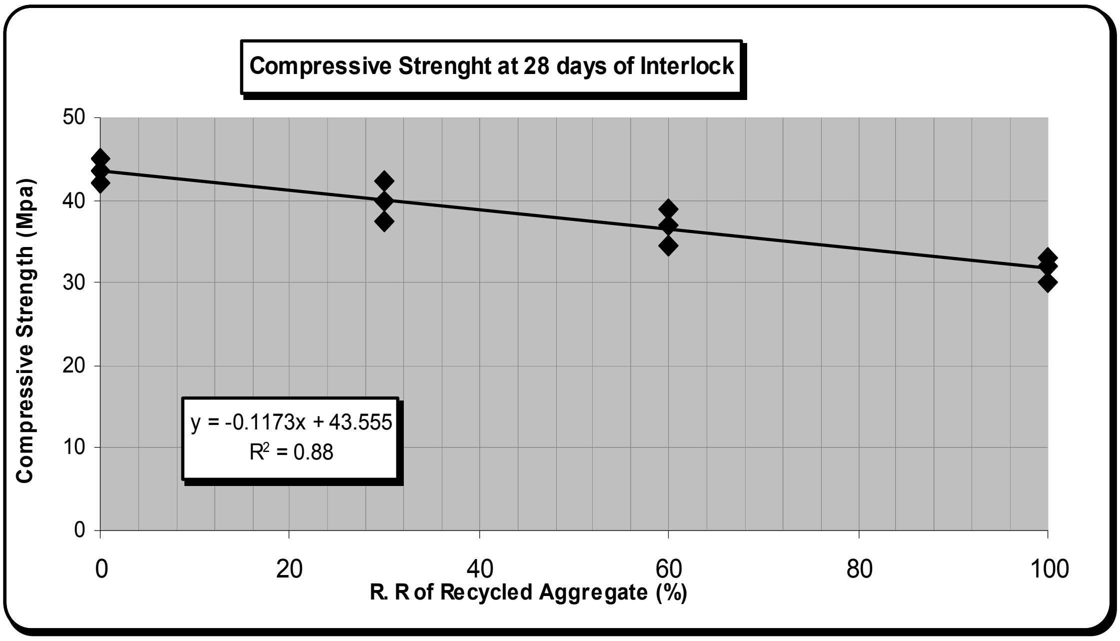

Figure 5.21 Compressive strength 28 days test for interlock at different R.R

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5.2.4 Abrasion Test

Figure 5.22 shows that there is a proportional relation between abrasion test and percentage content of recycled aggregate in interlock. Figure 5.22 also shows at 30%, 60% and 100% of recycled aggregate content, the results indicates an increase of 7%, 12% and 19 % respectively . Whereas natural aggregate is denser than recycled aggregate, so the time required to abrade natural aggregate interlock is longer than the time required to abrade recycled aggregate interlock. From this test results it was noticed that abrasion tests of interlock block samples which produced using recycled a aggregate apply standard requirement.

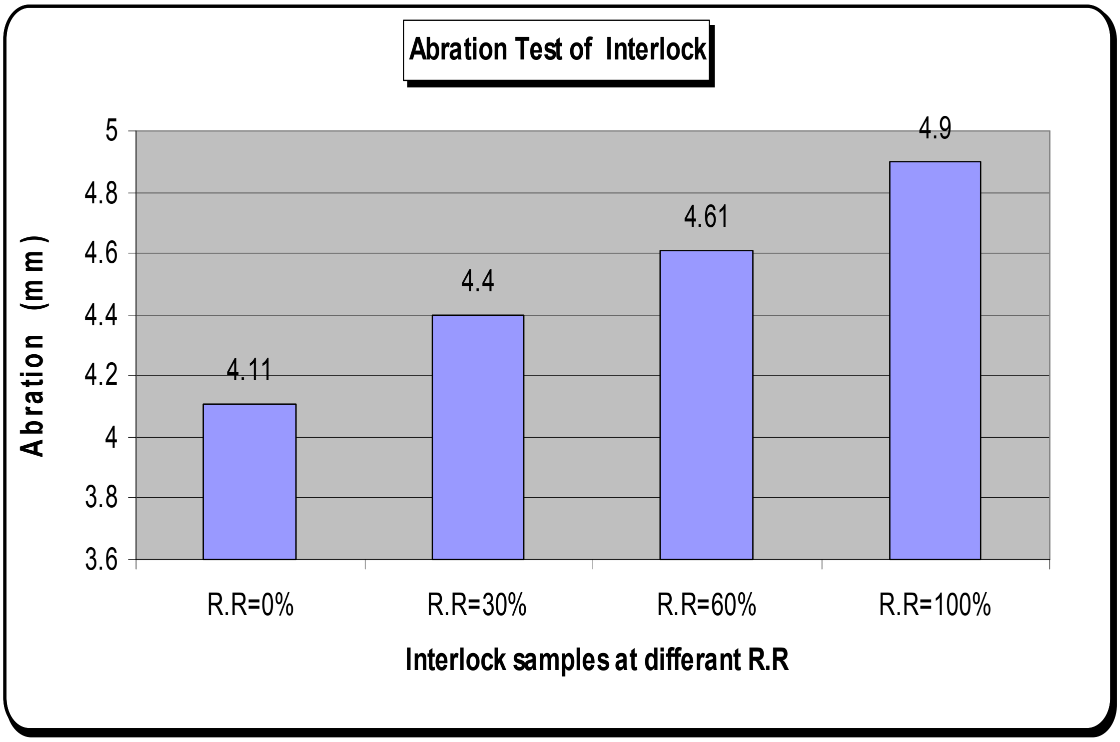

Figure 5.22 abrasion test for Interlock at different R.R

5.2.5 Relation Between Density and Compressive Strength

It is obvious from figure 5.23 that compressive strength test of interlock increase according to density increasing..

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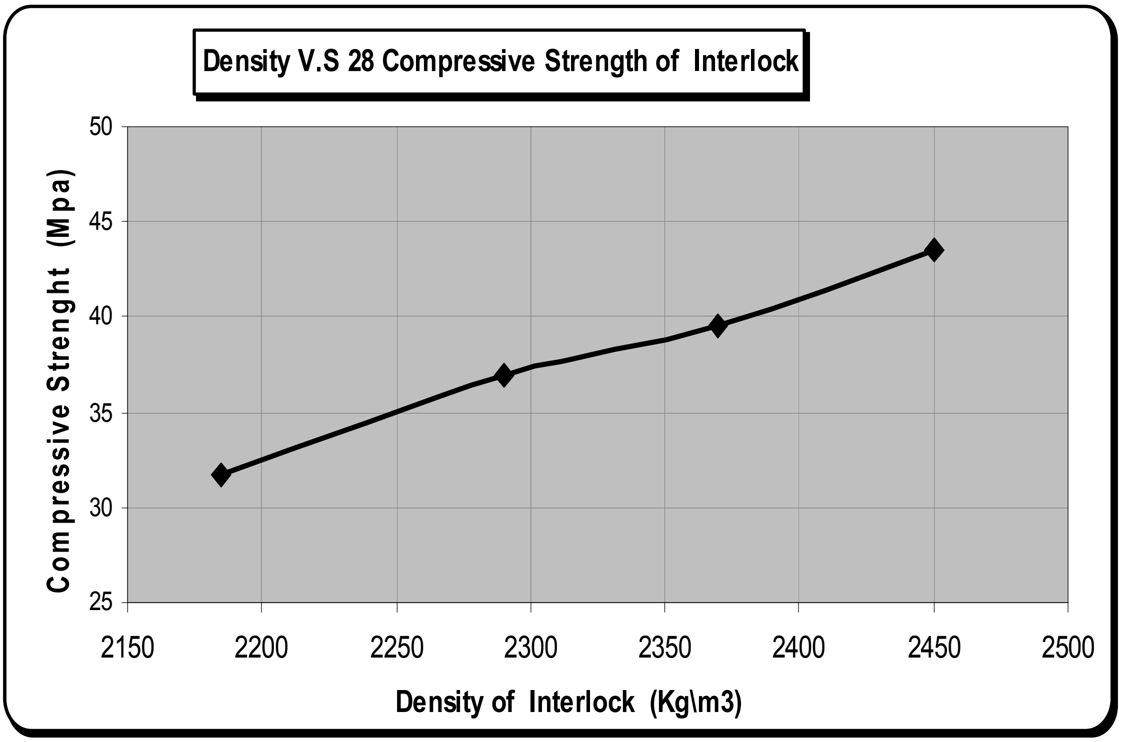

Figure 5.23 Relation between density and compressive strength

5.2.6 Relation Between Density and absorption Capacity

It seems from figure 5.24 that the absorption capacity results of interlock decreases according to the density increasing. This results is due to the aggregate in interlock with lower density, has higher porosity and permeability, which leads to higher absorption capacity.

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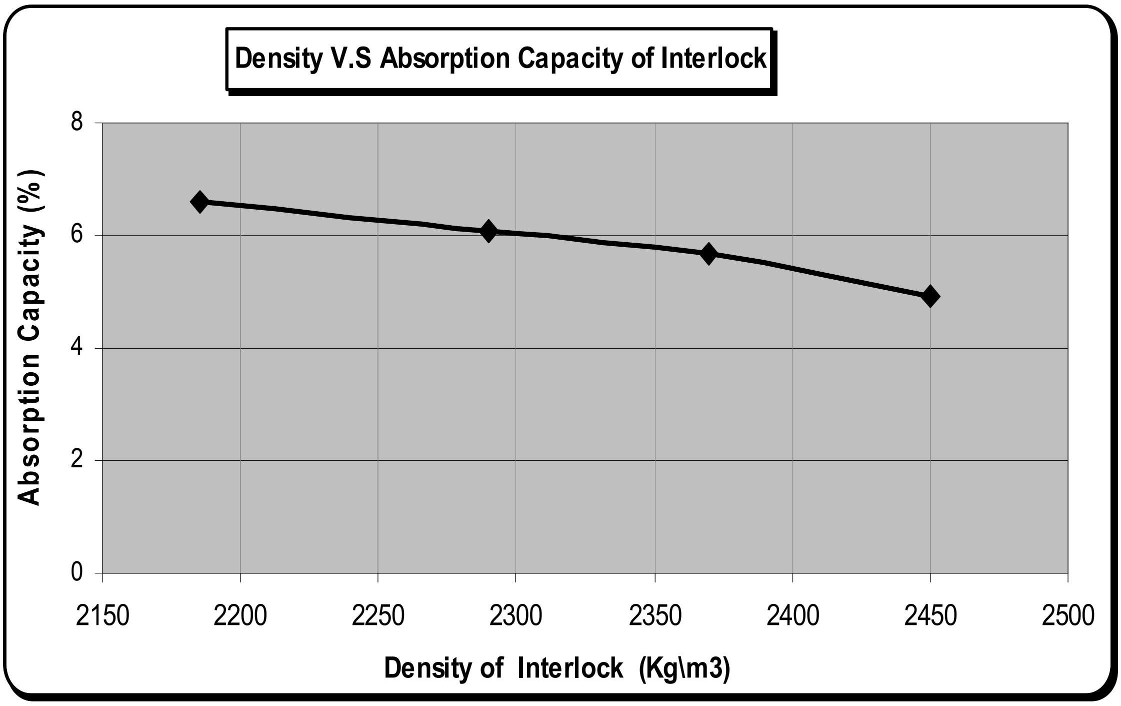

Figure 5.24 Relation between density and absorption capacity

5.3 Test effect of sea water on Recycled aggregate

This test aims to find the effect of sea water salts on block compressive strength. Figure 5.25 shows that the compressive strength test decreases according to recycled aggregate content increasing in block after 150 days of immersion in sea water.

It was demonstrated from this figure that the result is the same of 28 days block compressive strength results. From this figure, it was noticed that there is no clear change in test results between 28 days block compressive strength and compressive strength of block after 150 days immersion in sea water. In case it was expected that there is a reduction in compressive strength of sample that immerged by sea water due to reaction between contaminants in recycled aggregate and sea water salts, but this reduction doesn't occur due to short period of samples immersion in sea water. This result may differ after long time of sea water immersion.

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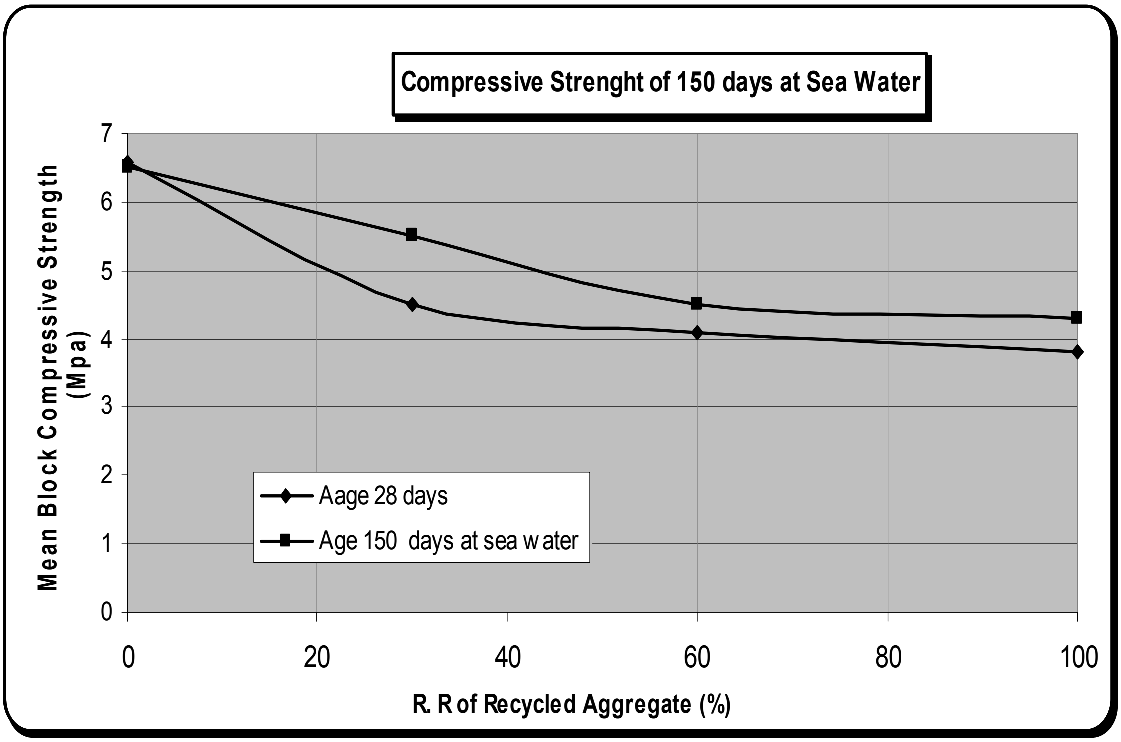

Figure 5.25 compressive strength of concrete block at 150 days in sea water

5.4 Testing the effect of high temperature on recycled aggregate

Table 5.8 illustrates the effect of high temperature on recycled aggregate concrete. In this test 60 cubic 100 mm were prepared using different content of recycled aggregate (0%, 30%, 60% and 100%).

Compressive strength test was performed after subjecting these samples to different temperature (20°C, 200°C, 400°C, 600°C and 800°C). Figure 5.26 also shows the effect of various degree of temperature at compressive strength of recycle aggregate concrete.

It seems from figure 5.26 that there is a reduction in recycle aggregate compressive strength due to temperature increasing; this reduction was 55 % of initial strength at 800 °C when using natural aggregate, but when using 100% recycled aggregate the reduction was 63 % of initial strength at 800°C .

The water content of the recycled concrete was expected to be higher than that of ordinary concrete, due to the greater water absorption of the recycled coarse aggregate. Generally speaking, the higher the water content, the higher the potential of the concrete spilling is expected in fire. However, spilling did not take place in any of the samples.

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Thus, the fire-resistant property of the recycled concrete is not considered to be significantly different from that of ordinary concrete.

It was indicated from this results that fire resistance of recycled aggregate concrete is as good as natural aggregate concrete.

Table 5.7 Reduction of compressive strength at different recycled aggregate content and different temperature

Temperature (C°)	20	200	400	600	800
R.R=0%	100	95	78	58	45
R.R=30%	100	93	81	59	43
R.R=60%	100	96	83	56	41
R.R=100%	100	97	79	54	37

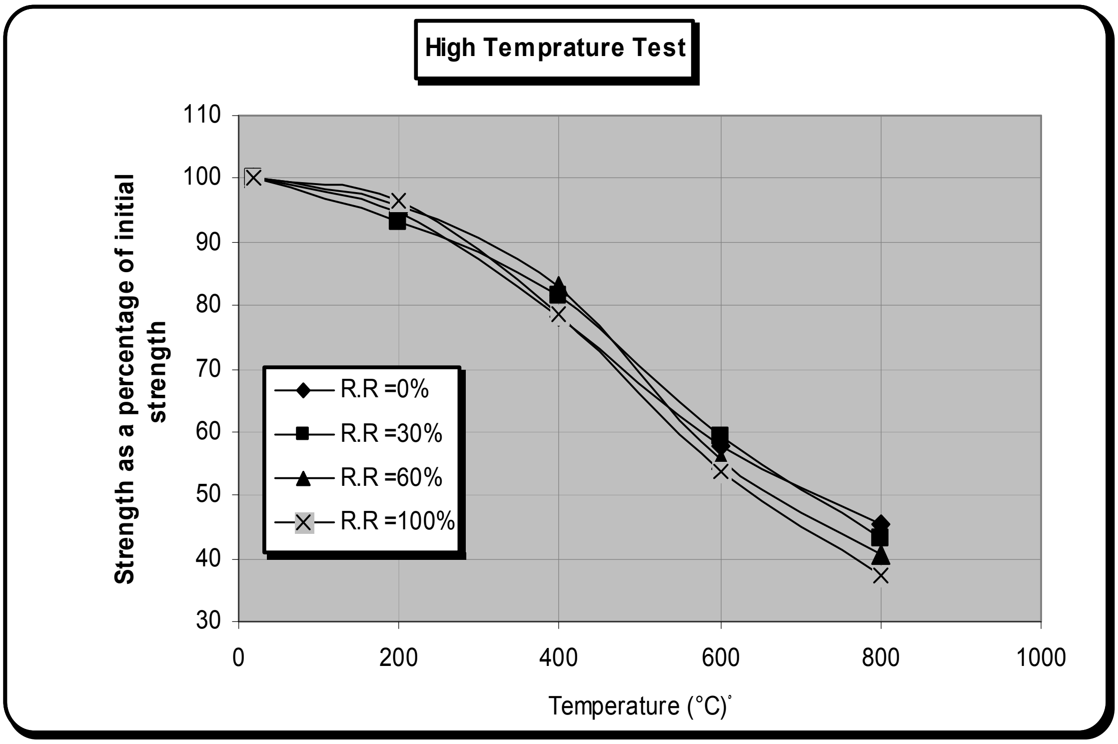

Figure 5.26 Reduction of compressive strength at different recycled aggregate content and different temperature

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Chapter Six

Conclusions and Recommendations

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6.1 Conclusion

Using of construction and demolition wastes in producing recycled aggregate has good potential for most construction application; It can be used as course aggregate in concrete block and concrete interlock.

6.1.1 Concrete properties

Recycle aggregate tests present high absorption capacity that reaches 5.9 %. These high results can be cured by immersion recycle aggregate in water before casting process. In comparison with natural aggregate, recycled aggregate presents low unit weight and specific gravity, but los angles abrasion test are much higher but its adequate for concrete application.

6.1.2 Concrete Block

Using recycle aggregate in producing concrete hollow block presents reduction 33 % in compressive strength when using 100% recycled aggregate, but this reduction decreases to 25 % when using 60 % recycled aggregate and 15 % when using 30% recycled aggregate. Concrete block can be produced using 100% recycled aggregate to get 4 MPa compressive strength which is adequate for concrete hollow block .

Compressive strength increases when increasing w/c ratio until 0.42 w/c ratio, but after that point, compressive strength decreases according to the increase of w/c ratio.

6.1.3 Concrete interlock

Compressive strength of interlocks reduced by 27 % when using samples of 100% recycled aggregate, but this reduction will be 15% at 60% recycled aggregate, and 9% at 30 % recycled aggregate .

Concrete interlock can be produced by using 100% recycled aggregate to give 32 MPa which is adequate for sidewalk and pedestrian roads

6.1.4 Durability tests

There is no clear effect of sea water on concrete block compressive strength made of recycled aggregate for 150 days immersion samples in sea water. This results due to the short period of immersion in sea water.

In comparison with concrete cubic samples made of recycled aggregate and natural aggregate at different temperature, reduction at compressive strength of recycled aggregate concrete samples is more than it in natural aggregate samples. This reduction for recycle aggregate samples at 800°C is 63 % , whereas the reduction in natural aggregate concrete sample at the same temperature is 55% .

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6.2 Recommendation

- Durability tests must be investigated and carefully studied using recycled aggregate on concrete block and block pavement
- Public awareness must be achieved about C&D wastes' problems and its effects, and importance of using this as new material in construction application to overcome this problem.
- A tests need to be concentrated on the effect of chemical attack on recycled aggregate, in case of high absorption capacity which can absorb higher amount of impurities.
- The effect of chemical substance that may react with contamination in recycled aggregate to increase the chemical reaction.
- Long term sea water test to investigate the effect of sea water on recycled aggregate

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Chapter Seven

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Appendix

Job Mix Design Procedure

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Job Mix Procedure and Example for Concrete Block

W/C = 0.42 based on filed data

Cement Content = 238.1 Kg/m3 based on field data

B.S.G.SSD of Aggregate = 2.66

B.S.G.SSD of Sand = 2.65
Air Content = 3.0 %

Moisture content (agg) = 1.2 %

Absorption capacity (agg) = 2.2 %

Moisture content (sand) =0 .5 %

Absorption capacity (sand) = 0.35 %

Water Content = 0.42 * 238.1 = 100 Kg/m3

Volume of Water = 0.100 m3

Volume of Cement = 238.1 / (3.15 * 1000) = 0.0755m3

Volume of Sand and Aggregate = 1 – [0.100 + 0.0755 + 0.035] = 0.7995 m3

Depending upon field observations during site visits to many factories it is obtained that:

In mixing process, Aggregate / Sand =3.5 (By Volume)

So, volume occupied by Sand = 0.222 * 0.7995 = 0.177 m3

Volume occupied by Aggregate = 0.777* 0.7995 = 0.621 m3

Weight of Sand = 0.177* 2650 = 469 Kg/m3

Weight of Aggregate = 0.621 * 2660 = 1651.86 Kg/m3

Adjustment for Moisture Content

Adjusted Water Content

= 100

+ [(2.2/100) – (1.2/100)]*1651.86

+ [(0..35/100) – (0.50/100)]* 472.54

= 115.8 Kg/m3

Adjustment for Aggregate and Sand

= 1651.86 * [1 – (2.2/100) + (1.2/100)]

= 1634 Kg/m3

= 472.54 * [1 – (0.35/100) + (0.5/100)]

= 470Kg/m3

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Mix Proportioning per Unit Volume Will be

Cement = 238.1 Kg

Water = 115.8 Kg (Free water)

Aggregate = 1634 Kg

Sand = 470Kg

Job Mix Procedure and Example for Concrete Block Pavement :

Step 1 : Finding water cement ratio (w/c)

From Figure A.1, the *w/c* required to produce an average 28 day strength of 50 Mpa in non air-entrained concrete is shown to be approximately 0.33 by mass.

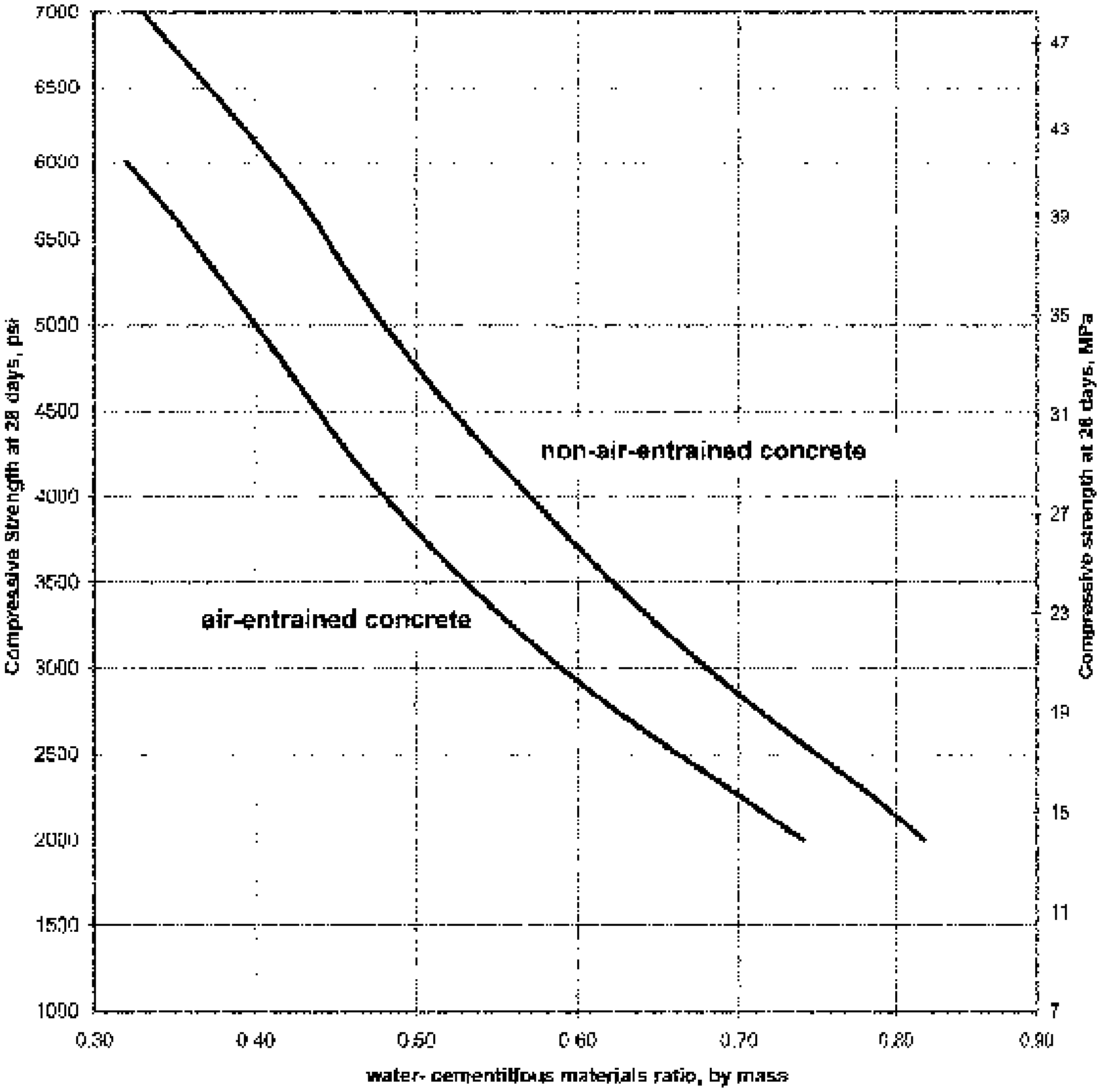

Figure A.1 Relationships between water-cementitious materials ration and compressive strength of concrete.

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Step 2 : Finding quantity of mixing water

From Figure A.2 the approximate quantity of mixing water needed to produce a consistency in the very stiff range in non air-entrained concrete made with 9.5 mm nominal maximum-size aggregate is to

be 190 kg /m3

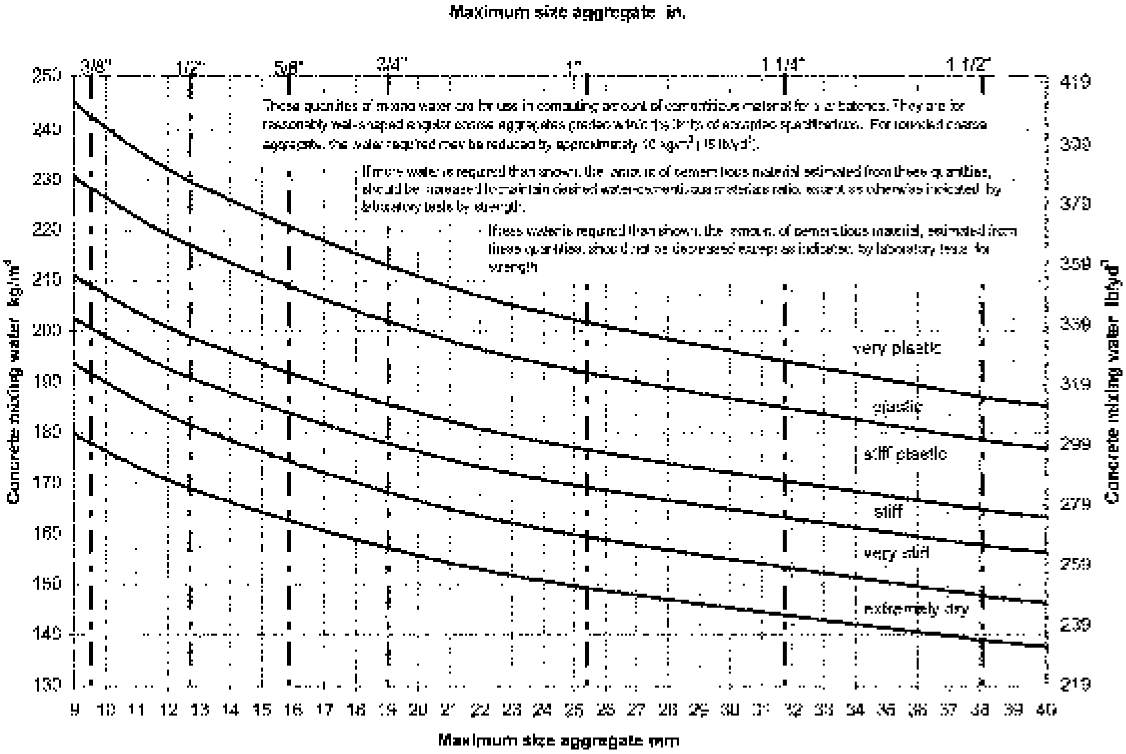

Figure A.2 Approximate mixing water requirements for different consistencies and maximum-size aggregate for non air-entrained concrete.

Step 3 : Finding air content

From Figure A.3 the desired air content is indicated as 3 % at non air-entraining

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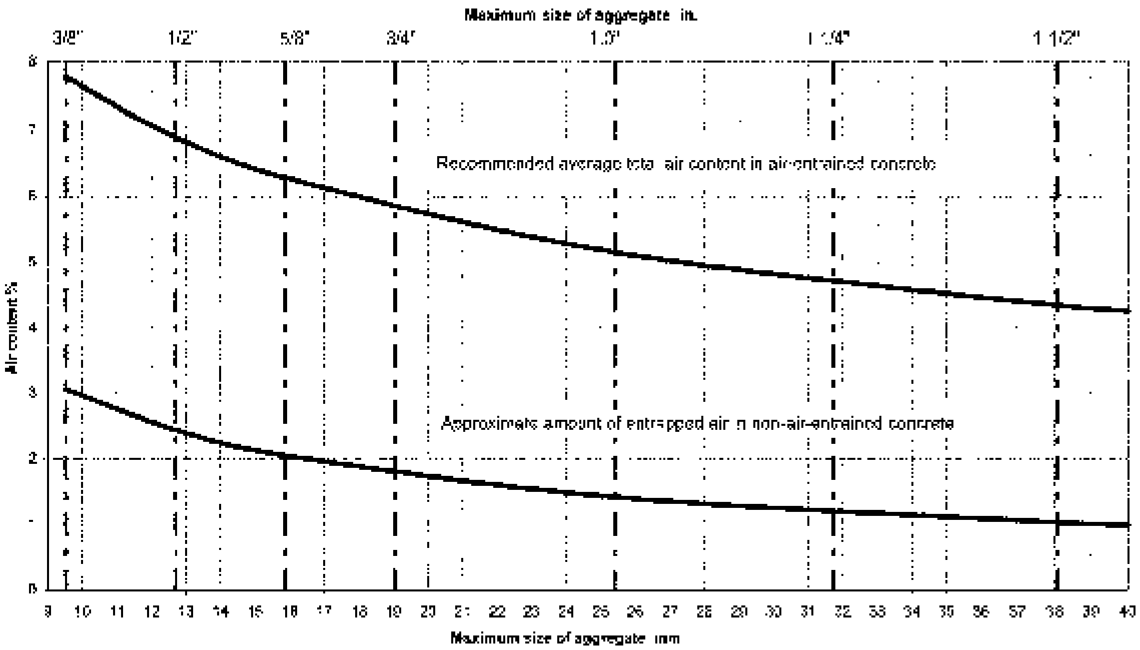

For consistencies below 25 mm (1 in.) slump, the volumes of air entrained by either an air-entraining cement or the usual amount of air-entraining admixture used for more plastic mixtures may be significantly lower than those shown.

Figure A.3 Air content of concrete mixtures for different maximum size aggregate.

Step 4 : Finding cemnt content

From the preceding two paragraphs, it can be seen that the required cementations material is 190/0.33 = 575 kg/m3. Portland cement only will be used

Step 5 Finding quantity of course aggregate

From Figure. A.4 with a nominal maximum-size aggregate of 3/8 in. and a fineness modulus of sand of 2.420, 0.50 m3 of coarse aggregate, on a dry-rodded basis, would be required in each cubic meter of concrete having a slump of about 3 to 4 in. and In Figure. A.5,for the very stiff consistency desired, the

amount of coarse aggregate should be 160% of that for the plastic consistency, or 0.50 × 1.60 = 0.80 m3 . The quantity in a cubic yard will be 0.80 , which in this case is 1595 × 0.80 , or 1276 Kg.

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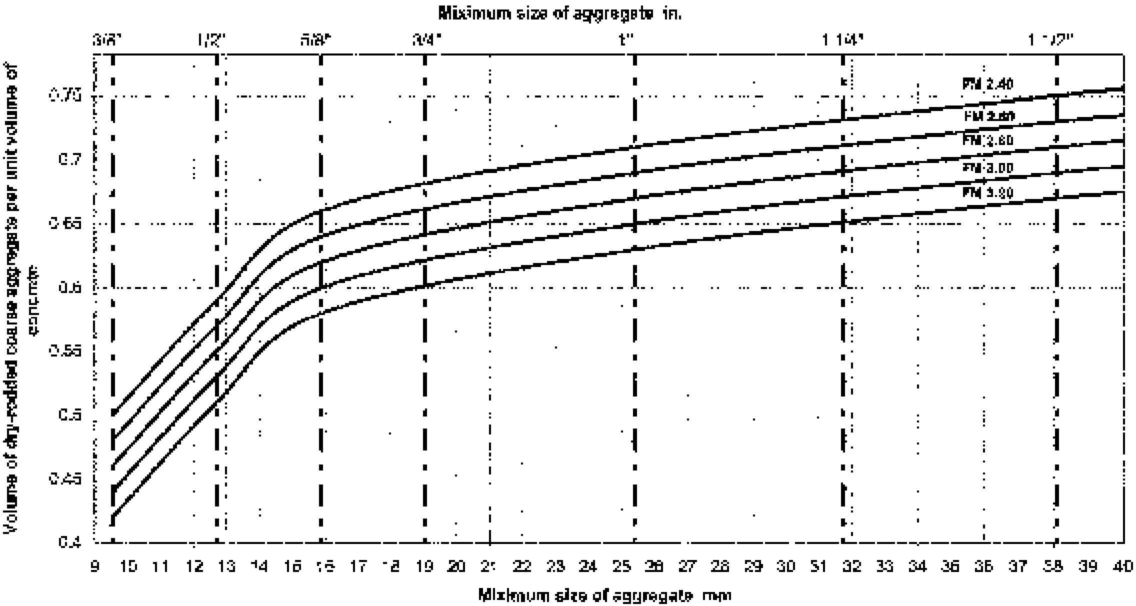

These volumes are selected from empirical relationships to produce concrete with a degree of workability suitable for usual construction.

Figure A.4 Volume of coarse aggregate per unit volume of concrete of plastic consistency (75 to 125 mm [3 to 5 in.] slump).

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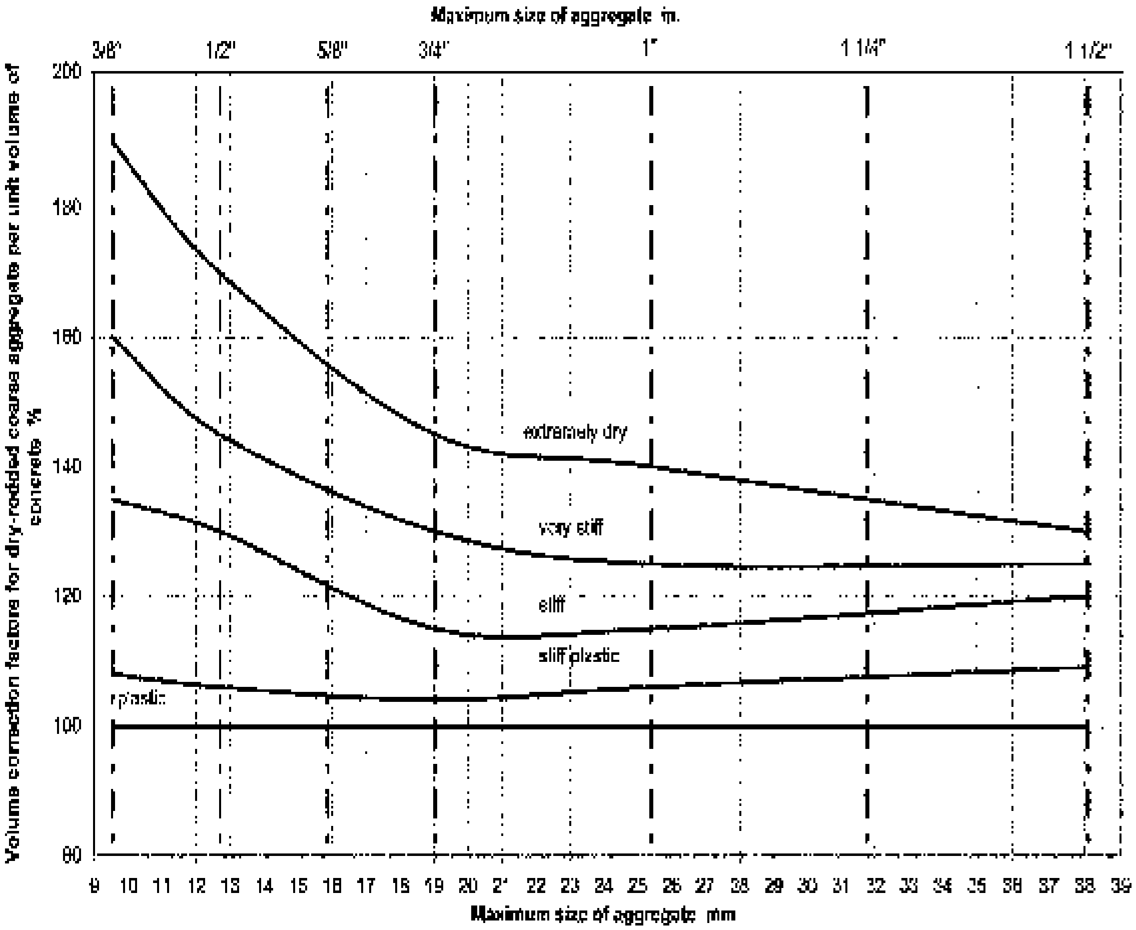

Based on tests of non-air-entrained concrete made with a natural sand having a fineness modulus of 2.90 and rounded gravel
containing particles of all the lower-size fractions. Maximum sizes were 9.5mm, 19mm, and 38.1mm (3/8", 3/4", and 1 1/2")
Values for 12.5mm and 25mm (1/2" and 1") are interpolated. It is assumed, for the purpose of this method, that the multiplication
factors are appropriate for sands having other fineness moduli. These values are intended as a guide in establishing the first trial mixtures.
Further adjustments will be necessary.

Figure A.5 Volume correction factors for dry-rodded coarse aggregate for concrete of different consistencies.

Step 6 : Finding Final quantities

With the quantities of cement, water, coarse aggregate, and air established, the sand content is calculated as follows: Solid volume of cement = [0.575 / 3.15] = 0.182m3

Volume of water = 0.190 m3

Solid volume of coarse aggregate = [1.18 / 2.66] = 0.44 m3

Volume of air = 0.03 m3

Total volume of ingredients except sand = 0.842 m3

Solid volume of sand required = 1.0– 0.842 = 0.158 m3

Required weight of oven-dry sand = [0.158 × 2.64] = 417 Kg

Water absorbed = [(417 × 0.001) + 1276 × 0.012)] = 15.35 Kg

The estimated batch quantities per cubic meter of concrete are:

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Cement = 575 Kg

Water = 205.35 Kg (190 + 15.35)

Sand, oven-dry = 417 Kg

Coarse aggregate, oven-dry = 1276 Kg

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Appendix

Research photos

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Figure B1: Recycled aggregate collection site	Figure B2: Recycled aggregate collection site
	
Figure B3 :Recycled aggregate collection site	Figure B4 : Crusher at collection site
	
Figure B5:Sieving recycled aggregate	Figure B6:Sieving recycled aggregate

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Figure B7:Casting concrete block process	Figure B8: Casting concrete block process
	
Figure B9:Process of interlock casting	Figure B10:Process of interlock casting
	
Figure B11:Absorption capacity and moisture content test	Figure B12: Absorption capacity and moisture content test

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Figure B13: Block compressive strength test	Figure B14: Absorption capacity and moisture content test
	
Figure B15: Interlock abrasion test	Figure B16: Block compressive strength test
	
Figure B17: high temperature test	Figure B18: high temperature test

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