# "Comparison of Properties of Recycled Aggregate Concrete with Conventional Concrete "

A PROJECT

*Submitted in partial fulfilment of the requirements for the award of the degree of*

**BACHELOR OF TECHNOLOGY**

IN

**CIVIL ENGINEERING**

under the supervision of

**Mr. Santu Kar**

**(Assistant Professor)**

by

***Ashwin Singh -121645***

***Shubhendu Gupta - 121648***

to

**JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY**

WAKNAGHAT, SOLAN – 173234

HIMACHAL PRADESH, INDIA

June, 2016

# CERTIFICATE

This is to certify that the work which is being presented in the project title **"Comparison of properties of Recycled Aggregate Concrete with Conventional Concrete"** in partial fulfilment of the requirements for the award of the degree of Bachelor of technology and submitted in Civil Engineering Department, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by **Ashwin Singh (121645)** and **Shubhendu Gupta (121648)** during a period from July 2015 to June 2016 under the supervision of **Mr. Santu Kar** Assistant Professor, Civil Engineering Department, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of our knowledge.

Date :

| | | |
|---|---|---|
| Dr. Ashok Kumar Gupta | Mr. Santu Kar | ............................ |
| Professor & Head of Department | Assistant Professor | External Examiner |
| Civil Engineering Department | Civil Engineering Department | |
| JUIT Waknaghat | JUIT Waknaghat | |

# ACKNOWLEDGEMENT

We wish to express our sincere thanks to Dr. Ashok kumar Gupta HOD. Civil, for providing us with all the necessary facilities for completing the project.

We place on record, our sincere thanks to Mr. Santu Kar, Assistant Professor, Civil for the continuos encouragement. We am extremely thankful and indebted to him for sharing expertise, and sincere and valuable guidance and encouragement extended to us.

We take this opportunity to express gratitude to all of the Department faculty members for their help and support.

Ashwin Singh ( 121645 )

Shubhendu Gupta ( 121648 )

# Abstract

One of the key challenge being faced by countries globally, is increasing "**construction and demolition waste (C&D) ".** Parallel with this demand for adopting techniques of concrete waste disposal is the demand for providing affordable housing to increasing global population. Now in order to provide affordable housing the overall cost of construction has to be reduced, this could be achieved by employing techniques, technologies and methods of project management. But if want to look for solutions through which we can mitigate the challenge of concrete waste disposal on one hand and decrease the cost of construction on the other hand, substitution of concrete with other cheap material is the way.

**"Recycled Concrete Aggregate (RCA) "** is conventional concrete substituted with recycled aggregates. Often a concrete after a duration of year or so has gone through cycles of creep and shrinkage strain. Due to these cycles of strain the coarse aggregates of the concrete loses a part of its strength. When this coarse aggregate is used as a substitute in freshly prepared concrete there is a slight reduction in the compressive strength of the concrete however under the ambit of standards set by various codes it becomes absolutely safe and economical to use. In this project itself, two concrete mix designs viz. M40 and M60 are taken for examining the percentage substitution of coarse aggregate that can allow for safe and economical usage in industries.

The criteria to decide the allowable percentage substitution is taken on the basis **"target mean strength"** which means any replacement of coarse aggregate with recycled aggregate that yields a strength greater than the target mean strength of the concrete (according to IS 456) will be considered safe.

The result of this experimental programme has shown that M40 can be fairly used up to fifty percent replacement of coarse aggregates with recycled aggregates and M60 can be used up to thirty percent replacement.

Decreasing the cost of concrete is both a market driven demand as well as has ecological high points. Through concrete substitution the overall carbon emission in disposal of concrete is reduced. Also it opens a market for new players which can benefit out of recycling of demolished concrete waste thereby increasing the value of waste and thereby bringing more active participation in the field of concrete waste disposal.

# TABLE OF CONTENT

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF ABBREVIATIONS

1. **C&D** - Construction and Demolition

2. **RCA** - Recycled Concrete Aggregates

3. $\mathbf{F_{ck}}$ - Characteristic Mean Strength

4. $\mathbf{F_{t}}$ **-** Target Mean Strength

5. **OPC** - Ordinary Portland Cement

6. **CTM** - Compression Testing Machine

7. **IS 8112** - Indian standard Code ( Properties of 43 Grade OPC )

8. **IS 10262:2009** - Indian Standard Code ( Mix Design Methodology )

9. **IS 516** - Indian Standard Code ( Compressive Strength Standards )

10. **IS 383:1970** - Indian Standard Code ( Grading of Fine Aggregates )

11. **IS 2386 (Part IV)** - Indian Standard Code ( Crushing Value and Impact Value of Aggregates )

12. **M40** - Mix of 40 Mpa Compressive Strength

13. **M60** - Mix of 60 Mpa Compressive Strength

14. **ACI** - American Concrete Institute

15. **PCC** - Plain Cement Concrete

# Chapter 1

# Introduction

## 1.1 General

Any construction activity requires several materials such as concrete, steel, brick, stone, glass, clay, mud, wood, and so on. However, the cement concrete remains the main construction material used in construction industries. For its suitability and adaptability with respect to the changing environment, the concrete must be such that it can conserve resources, protect the environment, economize and lead to proper utilization of energy. To achieve this, major emphasis must be laid on the use of wastes and by - products in cement and concrete used for new constructions. The utilization of recycled aggregate is particularly very promising as 75 per cent of concrete is made of aggregates. In that case, the aggregates considered are slag, power plant wastes, recycled concrete, mining and quarrying wastes, waste glass, incinerator residue, red mud, burnt clay, sawdust, combustor ash and foundry sand. The enormous quantities of demolished concrete are available at various construction sites, which are now posing a serious problem of disposal in urban areas. This can easily be recycled as aggregate and used in concrete. Research & Development activities have been taken up all over the world for proving its feasibility, economic viability and cost effectiveness. When structures made of concrete are demolished or renovated, concrete recycling is an increasingly common method of utilizing the rubble. Concrete was once routinely trucked to landfills for disposal, but recycling has a number of benefits that have made it a more attractive option in this age of greater environmental awareness, more environmental laws, and the desire to keep construction costs down. Research work is being carried out to determine whether it can be used for heavy construction works, however extensive results are not yet available. Recycled aggregates are currently used for low construction works such as construction of pavements etc.

Concrete has fairly unique properties and its recovery often falls between standard definitions of reuse and recycle. Concrete is rarely able to be “reused” in the sense of being reused in its original whole form. Nor is it “recycled” back into its original input materials. Rather, concrete is broken down into smaller blocks or aggregate for use in a new life. In this report “recycled concrete” refers to concrete that has been diverted from waste streams and reused or recovered for use in a new product. Concrete recycling is a well stabilised industry in many countries and most concrete can be crushed and reused as aggregate. Existing technology for recycling by means of mechanical crushing is readily available and relatively inexpensive. It can be done in both developed and developing countries. With further research and development, the scope of applications for recycled aggregate can be increased. However, even with existing technology, considerable increases in recovery rates can be achieved in some countries with greater public acceptance of recycled aggregate and reduction of misconceptions or ignorance about its possibilities for use. About 5% to 20% of concrete is made up of cement. Cement is made by crushing and blending limestone and clay (materials that contain oxides of calcium, silicon, aluminium and iron). The blend is then heated to about 1,500°C in a kiln and cement hydraulic materials, called clinker, are formed. Once the clinker is made, the materials are irreversibly bound. The clinker is then cooled and ground with a small proportion of gypsum and other additives to produce a dry powder – cement. Depending on the intended use, the ingredients in cement are varied in different products to improve properties such as strength, setting time, workability, durability and colour.

Cement production also uses recycled content such as slag and fly ash. Once concrete has been mixed, cement cannot be extracted from it for recycling. However, post-use or waste concrete can be recycled through the cement manufacturing process in controlled amounts, either as an alternative raw material to produce clinker or as an additional component when grinding clinker, gypsum and other additives to cement. Collection of recovery rate data is of more recent interest with growing concern regarding sustainable development and related indicators. That said, recycling concrete and C&DW is not new and has always been an element within construction due to the inert nature of concrete and the relative ease with which it can be processed into aggregate. Since early Roman times construction materials have been recycled and reused. In Europe large amounts of rubble after the Second World War were available for reuse in difficult economic times when infrastructure for exploitation and recovery of new materials was often restricted.

(Table 1.1)Amount of concrete waste generated by major places on globe

| Amount of Waste (Metric Tonnes) | Europe | USA | Japan |
|---|---|---|---|
| (1)Construction and demolition waste (C&DW) | 510 | 317 | 77 |
| (2)Municipal Waste | 241 | 228 | 53 |

Current data on recovery rates are hard to find to piece together a global picture. Data collection is not systematic beyond general data of C&DW generation and even that is not always available for all regions. Even when data is available, the definitions used vary. In general, recovery rates refer to waste that is diverted from landfill. For C&DW recovery data, some countries include excavated soil whereas others do not consider this within the definition of recovery. In Hong Kong, the extensive building and infrastructure development projects as well as the redevelopment of old districts have led to an increase in construction waste generation in the last two decades. The construction industry is the major solid waste generator. In order to manage such a huge quantity of construction waste in Hong Kong, the inert portion (e.g. debris, rubble, earth, concrete, bricks and rocks) of construction waste is deposited at public filling areas for land reclamation from sea and the non-inert portion (e.g. bamboo, timber, vegetation, packaging waste, organic materials) at municipal solid waste landfills. One of the aims of this disposal arrangement of construction waste is to minimize the amount needed for disposal so that the life span of the municipal landfills can be extended. On the other hand, in recent years, public concerns and objections have often delayed, stopped or reduced the scale of the implementation of planned reclamation projects. This has reduced the expected provision of reclamation sites and reduced the outlet capacity for the inert construction waste. Thus, there is a need to explore alternative uses of inert construction wastes so as to tackle the reduction in demand from reclamation sites for inert construction wastes (Poon et al., 2001).

The construction industry in Hong Kong consumes on average about 21 million tonnes aggregates each year. A large proportion, about 88%, is used as aggregate in the production of concrete. Asphalt production consumes around 5.5% and the remaining 6.5% is used in pavement sub-bases and other civil engineering works. It is estimated that each year about 2.3 million tonnes of recycled aggregate can be produced from the recyclable construction waste, out of which about 1.2 million tonnes could be utilized as pavement sub-bases, trench backfilling material and drainage fill, etc. This left around 1.1 million tonnes of recycled aggregates which should be utilized in the production of concrete (Cheng, 2000).

(Table 1.2)Myths and Reality related to Concrete Recycling

| **Myths** | **Reality** |
|---|---|
| Concrete cannot be recycled | Although concrete is not broken down into its constituent parts, it can be recovered and crushed for reuse as aggregate (for use in ready-mix concrete or other applications) or it can be recycled through the cement manufacturing process in controlled amounts, either as an alternative raw material to produce clinker or as an additional component when grinding clinker, gypsum and other additives to cement. |
| Recycled concrete aggregate cannot be used for structural concrete | It is generally accepted that about 20% (or more) of aggregate content can be replaced by recycled concrete for structural applications. |
| Although some concrete can be recycled it is not possible to achieve high rates | Countries such as the Netherlands and Japan achieve near complete recovery of waste concrete. |

| | |
|---|---|
| Concrete can be 100% made by recycling old concrete | Current technology means that recovered concrete can be used as aggregate in new concrete but (1) new cement is always needed and (2) in most applications only a portion of recycled aggregate content can be used (regulations often limit content as do physical properties, particularly for structural concrete). |
| Recycling concrete will reduce greenhouse gases and the carbon footprint | Most greenhouse gas emissions from concrete production occur during the production of cement. Less-significant savings may be made if transportation needs for aggregates can be reduced by recycling. |
| Recycling concrete into low-grade aggregate is down-cycling and is environmentally not the best solution | A full lifecycle assessment should be undertaken. Sometimes low-grade use is the most sustainable solution as it diverts other resources from the project and uses minimal energy in processing. That is not to say more refined uses might not also suit a situation. |
| Recycled aggregate is more expensive | This depends on local conditions (including transportation costs). |

## 1.2 Need of Study

Industry studies in Europe have shown a variation in the comparable profit margin as is illustrated in the following example. In Paris, a lack of natural aggregates makes recycled aggregate an attractive alternative, and the recycling market there is driven mainly by civil works companies with vertical integration of recycling outfits. Similarly in Rotterdam the profit margin for recycled aggregate is high but in this case it is due more to the selling price and despite higher production costs for recycled materials compared to virgin materials. In Brussels the lack of dumping possibilities means that construction and demolition companies drop the market price to find solutions for the waste, while in Lille the abundance of quarries make the higher production costs a limiting factor. Industry studies have shown that in Europe recycled concrete aggregate can sell for 3 to 12 € per tonne with a production cost of 2.5 to 10 € per tonne. The higher selling price is obtained on sites where all C&DW is reclaimed and maximum sorting is achieved, there is strong consumer demand, lack of natural alternatives and supportive regulatory regimes. Significant potential remains for increasing the use of coarse recycled aggregate in concrete. In some countries, notably Germany, Switzerland and Australia, concrete containing recycled aggregate is now being marketed. For example, Boral "green" concrete is premixed concrete using recycled aggregate that has been used in a number of building projects in Australia, including the world leading green building Council House 2, a 10-storey office block in Melbourne.

(Table 1.3)Rate of conversion of concrete waste is higher in US & Japan [Source : CSI Report 2009 ]

| **Material** | **Recycling rate Europe (%)** | **Recycling rate US (%)** | **Recycling rate Japan (%)** |
|---|---|---|---|
| Concrete/C&DW | 30 | 82 | 80 |
| Aluminium beverage cans | 58 | 52 | 93 |
| Aluminium in buildings | 96 | Not available | 80 |
| Glass containers | 61 | 22 | 90 |
| Lead acid batteries | 95 | 99 | 99 |
| Paper/cardboard | 63 | 56 | 66 |
| PET bottles | 39 | 24 | 66 |
| Tires | 84 | 86 | 85 |
| Steel containers | 66 | 63 | 88 |
| Wood | 16 | low | low |

Recycling concrete provides sustainability several different ways. The simple act of recycling the concrete reduces the amount of material that must be land filled. The concrete itself becomes aggregate and any embedded metals can be removed and recycled as well. As space for landfills becomes premium, this not only helps reduce the need for landfills, but also reduces the economic impact of the project. Moreover, using recycled concrete aggregates reduces the need for virgin aggregates. This in turn reduces the environmental impact of the aggregate extraction process. By removing both the waste disposal and new material production needs, transportation requirements for the project are significantly reduced.

A notable example from Germany is the Waldspirale complex containing 105 residential dwellings designed by Friedensreich Hundertwasser in Darmstadt. Completed in 2000, the building makes use of recycled aggregate in the concrete. Zürich’s largest school in Birch has led the way for the use of recycled aggregate in concrete in Switzerland. In Spain, Horcimex used recycled aggregate content in the structural concrete for a housing project in Madrid. To the extent that recycled aggregate is used in concrete, it tends to be mainly in ready-mix concrete. Reuse of blocks in original form, or by cutting into smaller blocks, has even less environmental impact; however, only a limited market currently exists. Improved building designs that allow for slab reuse and building transformation without demolition could increase this use. Hollow core concrete slabs are easy to dismantle and the span is normally constant, making them good for reuse.

(Table 1.4)Concrete Waste Recycling Scenario by Countries [Source : CSI Report 2009]

| **Country** | **Total C&D Waste** | **Total C&D Waste Recovery** | **% C&D Waste Recovery** |
|---|---|---|---|
| Australia | 14 | 8 | 57 |
| Belgium | 14 | 12 | 86 |
| Canada | N/A | 8 | N/A |
| Czech Republic | 9 | 1 | 45 |
| England | 90 | 46 | 50 – 90 |
| France | 309 | 195 | 63 |
| Germany | 201 | 179 | 89 |
| Ireland | 17 | 13 | 80 |
| Japan | 77 | 62 | 80 |
| Netherlands | 26 | 25 | 95 |
| Norway | N/A | N/A | 50 – 70 |
| Portugal | 4 | Minimal | Minimal |
| Spain | 39 | 4 | 10 |

| | | | |
|---|---|---|---|
| Switzerland | 7 | 2 | Near 100 |
| Taiwan | 63 | 58 | 91 |
| Thailand | 10 | N/A | N/A |
| US | 317 | 127 | 82 |

In addition to the resource management aspect, recycled concrete aggregates absorb a large amount of carbon dioxide from the surrounding environment. The natural process of carbonation occurs in all concrete from the surface inward. In the process of crushing concrete to create recycled concrete aggregates, areas of the concrete that have not carbonated are exposed to atmospheric carbon dioxide. The **LEED®** Green Building Rating System recognizes recycled concrete in its point system. Credit 4 (Materials and Resources) states, "specify a minimum of 25 percent of building materials that contain in aggregate a minimum weighted average of 20 percent post-consumer recycled content material, OR, a minimum weighted average of 40 percent post-industrial recycled content material." Using recycled aggregates instead of extracted aggregates would qualify as post-consumer. Because concrete is an assembly, its recycled content should be calculated as a percentage of recycled material on a mass basis. Credit can also be obtained for Construction Waste Management. It is awarded based on diverting at least 50 percent by mass of construction, demolition, and land clearing waste from landfill disposal. Concrete is a relatively heavy construction material and is frequently recycled into aggregate for road bases or construction fill.

## 1.3 Objective

**(1)** To investigate the use of recycled concrete aggregate replacing 20%,40%,45%,50%,55% & 60% of coarse aggregate by mass considering M40.

**(2)** To investigate the use of recycled concrete aggregate replacing 20%,25%,30%,35%,40% & 60% of coarse aggregate by mass considering M60.

**(3)** To suggest the safest and the most economic mix of recycled aggregate.

**(4)** To study the economic viability of the usage of recycled aggregates in concrete making.

## 1.4 Scope

The compressive strength and elastic modulus of concrete containing RA is lower than that of the control concrete. Recycled aggregate concrete is just as durable as ordinary concrete. However, prior to the use of RA concrete in aggressive environments, appropriate testing should be conducted. However the recycled aggregates used in this project are derived from one year old cast beams and cubes therefore the age of the construction and demolition waste is very less. The studies show that using recycled aggregates of greater age results in achievement of higher strength however this aspect has not been investigated in this project.

Recycled concrete aggregates contain not only the original aggregates, but also hydrated cement paste. This reduces the specific gravity and increases the porosity compared to similar virgin aggregates. The concrete produced with recycled aggregate loses its workability more rapidly than the conventional concrete, because recycled aggregate is more porous than natural aggregate. Thus concrete with recycled aggregate may require more mixing water to achieve the same workability as original aggregate. Since the concrete made in this project is devoid of application of plasticizers the workability of the fresh concrete makes it difficult to bring it in pumpable form. The recycled aggregates used in the project were crushed manually with the help of hammer and other manually crushing equipments. Hence the level of precision in regard to size of aggregates is less than aggregates derived from automatic aggregate crushing machines.

## 1.5 Project Methodology

1. Initially M40 and M60 design mix were taken and the coarse aggregates were replaced for following percentage viz 20%, 40% and 60%.
2. For M40, the cube failed to obtain satisfactory compressive strength after 28 days when the replacement percentage reached 60%.
3. For M60, cube replaced above 40% failed to obtain desired compressive strength.
4. To further decrease the range of replacement percentage an ideal variation of 5% was done in order to achieve more accurate replacement percentage.
5. For M40 new replacement percentage were 45%, 50% and 55%.
6. For M60 new replacement percentage were 25%, 30% and 35%.

Plain cement concrete (PCC) & reinforce cement concrete is collected from sites respectively. This collected material is crushed by hammer to separate the aggregates & reduce their sizes in smaller fraction. On these separated aggregates various testes are conducted in laboratory as per Indian Standard code & their results are compared with natural aggregates. Recycled aggregate reduces the impact of waste on environment. By using some percentage in construction sector, cost is saved, due to reduction of transportation & manufacturing process. The crushing characteristics of hardened concrete are similar to those of natural rock and are not significantly affected by the grade or quality of the original concrete. Recycled concrete aggregates contain not only the original aggregates, but also hydrated cement paste. This reduces the specific gravity and increases the porosity compared to similar virgin aggregates. The concrete produced with recycled aggregate loses its workability more rapidly than the conventional concrete, because recycled aggregate is more porous than natural aggregate. Thus concrete with recycled aggregate may require more mixing water to achieve the same workability as original aggregate. Recycled aggregates produced from good quality concrete can be expected to fulfil the requirements for the Los Angeles abrasion loss percentage, crushing and impact values.

# Chapter 2
# Literature Review

---

## 2.1 General

The aim for this project is to determine the strength and durability characteristics of high strength structural concrete by using recycled coarse aggregates, which will give a better understanding on the properties of concrete with recycled aggregates. The scope of this project is to investigate the possibility of using low cost recycled coarse aggregates as an alternative material to coarse aggregate in high strength structural concrete. Research on the usage of waste construction materials is very important because, construction waste materials is gradually increasing with the increase in population and increasing urban developments. The reason that many investigations and analysis had been made on recycled aggregate is because, recycled aggregate is easy to obtain and the cost is cheaper than natural aggregate.

## 2.2 Paper Description

**Research Paper**: *Experimental Studies on High Strength Concrete by using Recycled Coarse Aggregate.*
**Authors** : N.Sivakumar, S.Muthukumar, V.Sivakumar D.Gowtham, V.Muthuraj.
**Publication** : International Journal of Engineering And Science

The experimental investigation were carried out using detailed strength and durability related tests such as compressive strength test of cubes, split tensile strength test of cylinders, modulus of elasticity tests acid resistance test, test for saturated water absorption and porosity. The tests were conducted by replacing the coarse aggregates in high strength concrete mixes by 0, 10, 20, 30, 40 and 50% of recycled coarse aggregates. A 50% replaced mix with reduced w/c ratio was also tested. From the experimental investigation it was found that recycled coarse aggregates can be used for making high strength concretes by adjusting the w/c ratio and admixture contents of the mix. The aim for this project was to determine the strength and durability characteristics of high strength structural concrete by using recycled coarse aggregates, which will give a better understanding on the properties of concrete with recycled aggregates. The scope of this project was to investigate the possibility of using low cost recycled coarse aggregates as an alternative material to coarse aggregate in high strength structural concrete. The target compressive strength (40MPa) can be achieved for 30 to 40 % of RCA replacement by decreasing the water cement ratio and adjusting the admixture content of mix. This is classified as high strength concrete and can be applied in infrastructures, which need compressive strength up to 40MPa. Another result found in this research is that when reducing the water cement ratio used in recycled aggregate mixes, tensile strength and modulus of elasticity are also improved. This will give an improvement in general strength characteristics of structural building. The percentage loss in weight of concrete cubes after the conduct of acid resistance test is negligible for 30 to 40% RCA replacements. Moreover reduction in the strength is also nominal, which shows that these mixes were less attacked by acid. The water absorption and porosity of RCA replaced mixes are higher than normal mix but within the permissible limits. These properties can be modified by reducing the w/c ratio and by incorporating admixtures.

**Research Paper** :Studies *on Strength and Related Properties of Concrete Incorporating Aggregates from Demolished Wastes: Part 1—A Global Perspective* -
**Authors** : S. Franklin, M. T. Gumede
**Publication** : Open Journal of Civil Engineering

The present study addresses the global concern of sustainability in building and construction engineering and how to an extent the use of demolished aggregate wastes in concrete production contributes towards ameliorating or minimizing the problem. The influence of demolished aggregate waste on the mechanical strength and stiffness of concrete are examined from the standpoint of the compressive, split tensile and flexural strengths as well as the modulus of elasticity of the concrete. In this respect the research carried out by previous investigators are noted. It is observed that in the Southern African region in general and Botswana in particular there is a paucity of studies on the subject, and consequently, it is concluded that further investigations need to be conducted utilizing aggregates derived from local wastes or sources. The present work, albeit a comprehensive review, represents a preliminary portion of an on-going investigation by the authors on the assessment of the strength of concrete incorporating aggregates from demolished wastes. The investigation is expected to include experimental studies involving demolished concrete wastes collected from some major dump sites in Gaborone the capital city of Botswana. From the study carried out herein, a number of conclusions may be drawn. It is obvious that structural compressive strengths may be developed in concretes incorporating up to 100% recycled aggregates based on standard mix design procedures. We note also that the compressive, split tensile and flexural strengths, as well as the modulus of elasticity of recycled aggregate concretes, are generally lower than that of conventional concretes made entirely from natural aggregates. The reduction in strength is dependent on several factors such as the type of concrete used in obtaining the recycled aggregates, the replacement ratio, the water-cement ratio and the moisture condition of the recycled aggregates. Additionally we observe that in the Southern African sub-continent including Botswana, apart from investigations on construction waste management practices, there has been practically no study to the best of the authors' knowledge on the relative strength of concrete incorporating aggregates from demolished wastes.

**Research Paper** :*Compressive Strength of Concrete Using Recycled Concrete Aggregate as Complete Replacement of Natural Aggregate*
**Authors** : Daniel Yaw Osei
**Publication** : Journal of Engineering, Computers & Applied Sciences

This paper presents a report of an experimental investigation on the effect of complete replacement of natural aggregate by recycled concrete aggregate in the production of concrete on the compressive strength of concrete. Two sets of concrete mixtures of ratios 1:3:6, 1:2:4, 1:11/2:3, 1:1:2 by mass were cast using natural aggregates and recycled aggregates concrete respectively. The 28-day compressive strengths of 1:3:6, 1:2:4, 1:11/2:3, 1:1:2 concrete using recycled concrete aggregates were 12.18 Nmm-2, 17.14 Nmm-2, 21.65 Nmm-2 and 25.81Nmm-2 respectively corresponding to 33%, 20%, 11% and 20% reduction in strength compared to concrete using natural aggregate.. The densities and compressive strengths of natural aggregate concrete were higher than that of corresponding recycled aggregate concrete. The results of the study showed that recycled concrete aggregate can potentially replace completely natural aggregate in the production of both non-structural and structural concrete.

**Research Paper** :*Use of Recycled Aggregate Concrete*
**Authors** : T Sonawane, S  Pimplikar
**Publication** : Journal of Mechanical and Civil Engineering

Use of recycled aggregate up to 30% does not affect the functional requirements of the structure as per the findings of the test results. Various tests conducted on recycled aggregates and results compared with natural aggregates are satisfactory as per IS 2386. Due to use of recycled aggregate in construction, energy & cost of transportation of natural resources & excavation is significantly saved. This in turn directly reduces the impact of waste material on environment.

**Research Paper** : *Use Of Recycled Concrete Aggregate in Making Concrete*
**Author** : S R Yadav
**Publication** : 34thConference on Our World in Concrete & Structures: 16 - 18 August 2009, Singapore

Research work has concluded that a 25- 30% recycled may not have significant effect on concrete properties, but if these aggregates contain more than 65% of adhered mortar its impact on concrete properties have not been evaluated. Hence it would be necessary to understand what % of adhered mortar could be tolerated on recycled aggregates in making concrete and also calculate the % replacement based on % adhered mortar. The work thus would simplify the work for contractors who would be interested in using demolished concrete and give a simple procedure of using recycled by considering % adhered mortar and evaluating the mix proportions for attaining a comparable strength for high grade applications.

**Report** : *Use of recycled aggregates in concrete- A Paradigm Shift*

**Author:** S. K. Singh, Scientist, Structural engineering Division, Central Building Research Institute, Roorkee and P. C. Sharma, Head ( Retd.), Material Sciences, SERC,(G) and Editor New Building Materials & Construction World, New Delhi, Chairman, Indian Concrete Institute. UP Ghaziabad Centre.

The development of compressive strength of recycled aggregate concrete at the age of 1,3,7,14,28, 56, and 90 days; the development of tensile & flexural strength at the age of 1,3,7,14 and static modulus of elasticity at the age of 28 days are investigated. The results shows the compressive, tensile and flexural strengths of recycled aggregate are on average 85% to 95% of the natural aggregate concrete. The durability parameters are also investigated for recycled aggregate concrete and are found to be in good agreement with BIS specifications.

**Research paper** : Use of recycled concrete aggregate in high-strength concrete

**Author** : M. C. Limbachiya, T. Leelawat and R. K. Dhir

**Publication** : Concrete Technology Unit, Department of Civil Engineering, University of Dundee, Dundee DD1 4HN, Scotland, UK

The results of a test programme to study the use of recycled concrete aggregate (RCA) in high-strength, 50 N/mm 2 or greater, concrete are described. The effects of coarse RCA content on the ceiling strength, bulk engineering and durability properties of such concretes have been established. The results showed that up to 30% coarse RCA had no effect on concrete strength, but thereafter there was a gradual reduction as the RCA content increased. A method of accommodating the effects of high RCA content, involving simple adjustment to water/cement ratio of the mix is given. It is shown that high-strength RCA concrete will have equivalent engineering and durability performance to concrete made with natural aggregates, for corresponding 28-day design strengths.

**Report** : *Case Study : O' Hare Modernization Project*

**Author** : PCA America Cement Manufacturer

Recycled concrete aggregates are being considered for use in the O’Hare Modernization Project (OMP). Laboratory testing using a two-stage mixing method showed that using RCA from Chicago O’Hare International Airport for the coarse aggregate reduces bleeding and segregation and produces similar workability, compressive strength, and shrinkage as virgin aggregates. In October of 2009, a field test of RCA was initiated in two lanes at Gate F7B. In a side-by-side comparison, a lane of concrete using virgin aggregates was placed next to a lane of concrete using RCA. The RCA was produced on-site using concrete removed at the airport. The ready mixed concrete supplier treated the RCA like lightweight aggregates and was able to produce concrete in a single-stage mixing process. Contractors placing the RCA concrete said the workability was similar to that of the virgin aggregate concrete and the placement had good finish ability. Within four days, the placement was in full service. Sensors were placed in the concrete at the time of placement to measure the internal relative humidity, temperature, and the lift-off of the slab from the cement-treated permeable base. Other properties were regularly monitored, such as surface appearance and joint width. After five months of monitoring, the data between the two concrete lanes are statistically the same, showing no difference in behaviour between the RCA concrete and virgin aggregate concrete.

**Research paper :** *Use of recycled aggregate in moulded block and bricks*

**Authors :** C. S. Poon, S. C. Kou and L. Lam

**Publication :** The Hong Kong Polytechnic University Hung Hom, Kowloon, Hong Kong

This study aimed to develop a technique for producing concrete bricks and paving blocks using recycled aggregates obtained from construction and demolition waste. Laboratory trials were conducted to investigate the possibility of using recycled aggregates from different sources in Hong Kong, as the replacement of both coarse and fine natural aggregates in moulded bricks and blocks. A series of tests were carried out to determine the properties of the bricks and blocks prepared with and without recycled aggregates. The test results showed that the replacement of coarse and fine natural aggregates by recycled aggregates at the levels of 25 and 50% had little effect on the compressive strength of the brick and block specimens, but higher levels of replacement reduced the compressive strength. However, the transverse strength of the specimens increased as the percentage of replacement increased. Using recycled aggregates as the replacement of natural aggregates at the level of up to 100%, concrete paving blocks with a 28-day compressive strength of not less than 49 MPa can be produced without the incorporation of fly ash, while paving blocks for footway uses with a lower compressive strength of 30 MPa and masonry bricks can be produced with the incorporation of fly ashes.

**Research Paper :** *Use of aggregates from recycled construction and demolition waste in concrete*

**Authors :** Akash Rao , Kumar N. Jha  Sudhir Misra

**Publication :** Science Direct

This paper discusses different aspects of the problem beginning with a brief review of the international scenario in terms of C&D waste generated, recycled aggregates (RA) produced from C&D waste and their utilization in concrete and governmental initiatives towards recycling of C&D waste. Along with a brief overview of the engineering properties of recycled aggregates, the paper also gives a summary of the effect of use of recycled aggregate on the properties of fresh and hardened concrete. The paper concludes by identifying some of the major barriers in more widespread use of RA in recycled aggregate concrete (RAC), including lack of awareness, lack of government support, non-existence of specifications/codes for reusing these aggregates in new concrete

**Research Paper :** *Mechanical behaviour of concrete made with fine recycled concrete aggregates*

**Authors:** L. Evangelista , J. de Brito

**Publication :** Elsevier

This paper concerns the use of fine recycled concrete aggregates to partially or globally replace natural fine aggregates (sand) in the production of structural concrete. To evaluate the viability of this process, an experimental campaign was implemented in order to monitor the mechanical behaviour of such concrete. The results of the following tests are reported: compressive strength, split tensile strength, modulus of elasticity and abrasion resistance. From these results, it is reasonable to assume that the use of fine recycled concrete aggregates does not jeopardize the mechanical properties of concrete, for replacement ratios up to 30%.

**Research paper :** *Recycled concrete aggregates*

**Authors :** Nik. D. Oikonomou

**Publication :** Cement & Concrete Composites conference, 2005, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

In the present work a guidance of tests and limits of RCA is proposed in order to be used as a basis for pilot and long scale works where the use of RCA can be estimated as more economic and friendlier to the environment. In practical terms, for Greece an experimental use of RCA for a pilot structure is proposed during a first phase, with the addition of only coarse aggregate (>4.75 mm) up to 30% which should comply with the proposed specifications. The subject of RCA use in works in Greece is considered especially urgent, because of the big projects for the Olympic Games of 2004 in Athens.

# Chapter 3

# Experimental Program

## 3.1 General

The entire experimental program is dependent upon careful selection as well as gradation of aggregates. So in regard to selection of aggregate two types of aggregates have been chosen. One category of aggregate of 20mm nominal size and other of 10mm nominal size. Following aggregates have been obtained from the concrete waste in the form of RCC beams kept in the civil engineering LAB. Prior to aggregate gradation, the selection of material becomes very important. To ascertain whether the materials procured are of good quality, certain preliminary tests have to be followed. Also in regard to aggregates the crushing test value as well as abrasion values play a very important role in judging the character of aggregates.

## 3.2 Materials

The material required for concrete making includes cement, coarse aggregates, fine aggregates and water. The plasticizers and super plasticizers were not used in this experimental program. Along with the aforesaid material recycled aggregates were used in their surface saturated condition. The age of recycled aggregate chosen is of one year. With more age the creep shrinkage of aggregates increases which decreases its productivity as an aggregate.

### 3.2.1 Cement

Ordinary Portland Cement of Grade 43 was used. Before using the cement as a primary check it was made to pass through the 90 micron sieve. The specific gravity of the cement is 2.83 making it usable for experimental purpose. The initial setting time of the cement was found to be 30 minutes while the final setting time was found to be 630 minutes.

(Table 3.1) Characteristics of Cement Used

| Specific Gravity | Initial Setting Time | Final Setting Time |
|---|---|---|
| 2.83 | 30 mins | 10.5 hrs |

### 3.2.2 Aggregates

The Specific gravity of the coarse as well as the fine aggregates was found to be equal to 2.65. The sorting or selection of aggregates for 20mm and 10mm nominal size was based on sieve analysis. Sub angular aggregates were used which offer medium to high workability. However the plasticizers were not used and the water/cement ration is maintained low thereby concrete showing less workability was obtained. In case of recycled aggregates cast beams of age one year were used. Fine Aggregate of zone II was used.

(Table 3.2) Characteristics of coarse aggregates used

| Specific Gravity | Crushing Value | Abrasion Value |
|---|---|---|
| 2.65 | 45% | 38 % |

Specific gravity of fine aggregates : 2.65

## 3.3 Equipment Used

Various equipments ranging from slump cone apparatus to sieve shaker or compression testing machine were used. In few cases rapid curing incubator was used to eliminate the time constraints and similarly mechanical vibrators were used instead of adopting hand sieving.

(Table 3.3) Detail of Equipments/Machines Used

| **Sr. No.** | **Material/Machine list** | **Specification** | **Remark** |
|---|---|---|---|
| 1 | Drum Mixer | The Drum Mixer is used for mixing of concrete. It is used for a duration of maximum 5 minutes for mixing material for three cubes. | Hand mixing leads to increase in time of mixing and ultimately decrease in workability of concrete. Therefore the drum mixer should be used for all mixing operations. |
| 2 | Sieve Shaker | Sieve Shaker for grading fine aggregates is used. It was used for a duration of 3 minutes for a fine aggregate sample of 1 kilogram. | Either 100 mechanical shakes or sieving for 3 minutes through machine was adopted. |

| | | | |
|---|---|---|---|
| 3 | Compressive Testing Machine | CTM for measuring the compressive strength of the cubes of side 15cm and 10cm. The tensile strength of the cubes were ignored. | |
| 4 | Mechanical Vibrator | For compacting the cubes of concrete. The use of mechanical vibrator is permitted til the top surface becomes even. | |
| 5 | Slump Cone | Slump Cone for measuring the slump loss in concrete. The slump value to be used for our mix design calculations. | The slump loss varied from 17mm to 29mm. The loss in slump depends much upon the type of aggregates and water/cement ratio. |
| 6 | Cube Mould | Cube Mould of size 15cm and 10cm is used. | |
| 7 | Rapid Curing Incubator | For achieving the 28days strength in 3 days. | |
| 8 | Curing Tank | For curing of cubes. | The duration for optimal strength is increased due to low temperature. However the duration for estimating the target mean strength has been fixed for the process as 28 days. |
| 9 | Digital Weight Machine | For measuring the weight of materials. | |

## 3.4 Mix Design

Concrete like other engineering materials needs to be designed for properties like strength, durability, workability and cohesion. Before having any concrete mixing, the selection of mix materials and their required materials proportion must done through a process called mix design. With advent of high-rise buildings and pre-stressed concrete, use of higher grades of concrete is becoming more common. Even the revised **IS 456-2000** advocates use of higher grade of concrete for more severe conditions of exposure, for durability considerations. In this project IS Method of Design shall be used. Concrete cubes each from the HSC mix and the HSC mix with percentage replacements of RCA is to be caste and tested for its durability by conducting the following tests. Aim of this research project is to determine the strength and durability characteristics of recycled aggregate for potential application in the high concrete structural concrete.

(Table 3.4) Table for target mean strength and minimum grade of concrete suggested by IS 456:2000

| Nominal Aggregate Size is 20mm<br>Specific Gravity of cement is 2.83 | | | Exposure condition is Moderate<br>Air Content is assumed to be 2% | | |
|---|---|---|---|---|---|
| $f_{ck}$ | $f_t$ | Water/Cement (from graph) IS 8113 | Min Grade | Min Cement (kg) | Adjustment 1 (10mm agg.) |
| 25 | 31.6 | 0.48 | M15 | 240 | 280 |
| 30 | 38.25 | 0.4 | M15 | 240 | 280 |
| 35 | 43.25 | 0.36 | M15 | 240 | 280 |
| 40 | 48.25 | 0.33 | M15 | 240 | 280 |
| 45 | 53.25 | 0.3 | M15 | 240 | 280 |
| 50 | 58.25 | 0.3 | M15 | 240 | 280 |
| 55 | 63.25 | 0.3 | M15 | 240 | 280 |
| 60 | 68.25 | 0.3 | M15 | 240 | 280 |

(Table 3.5) Values for water content and adjustments due to angularity of aggregates

| Specific Gravity of Coarse Aggregate is 2.65<br>Specific Gravity of Fine Aggregate is 2.65 | | | |
|---|---|---|---|
| Water Content (kg) (SSD) | | Adjustment 2 (Sub-angular Aggregates.) | Adjustment 3 (Slump) |
| M25 | 186 | 176 | |
| M30 | 186 | 176 | |
| M35 | 186 | 176 | |
| M40 | 186 | 176 | 29mm slump loss |
| M45 | 186 | 176 | |
| M50 | 186 | 176 | |
| M55 | 186 | 176 | |
| M60 | 186 | 176 | 17mm slump loss |

(Figure 3.1)

Slump Cone Test of fresh concrete

(Table 3.6) Table shows the value of cement content according to 1m$^3$ concrete.

| Maximum Water/Cement Ratio is 0.6 | | | | |
|---|---|---|---|---|
| $f_{ck}$ | Cement Content (kg) | Zone of Aggregate | | Volume of Aggregates. Va (m$^3$) |
| | | Zone | Value p | |
| 25 | 367 | II | 0.66 | 0.6876 |
| 30 | 440 | II | 0.66 | 0.6643 |
| 35 | 489 | II | 0.66 | 0.6488 |
| 40 | 533 | II | 0.66 | 0.6347 |
| 45 | 587 | II | 0.66 | 0.6178 |
| 50 | 587 | II | 0.66 | 0.6178 |
| 55 | 587 | II | 0.66 | 0.6178 |
| 60 | 587 | II | 0.66 | 0.6178 |

(Table 3.7) Table shows the weight and volume of aggregates taken per 1m$^3$ concrete

| Fine Aggregate | | | Coarse Aggregate | |
|---|---|---|---|---|
| $f_{ck}$ | Volume | (kg) | Volume | (kg) |
| 25 | 0.2338 | 620 | 0.4538 | 1203 |
| 30 | 0.2259 | 599 | 0.4384 | 1162 |
| 35 | 0.2206 | 585 | 0.4282 | 1135 |
| 40 | 0.2158 | 572 | 0.4189 | 1110 |
| 45 | 0.2100 | 557 | 0.4077 | 1080 |
| 50 | 0.2100 | 557 | 0.4077 | 1080 |
| 55 | 0.2100 | 557 | 0.4077 | 1080 |
| 60 | 0.2100 | 557 | 0.4077 | 1080 |

(Table 3.8) Composition of materials for M40 Grade Concrete for various replacement percentages for $1m^3$

| Material (kg) | Replacement Percentage | | | | | |
|---|---|---|---|---|---|---|
| w/c = 0.33 | 20% | 40% | 45% | 50% | 55% | 60% |
| Water | 175 kg | 175 kg | 175 kg | 175 kg | 175 kg | 175 kg |
| Cement | 533 kg | 533 kg | 533 kg | 533 kg | 533 kg | 533 kg |
| Coarse Aggregates | 887 kg | 665 kg | 612 kg | 555 kg | 499 kg | 444 kg |
| Fine Aggregates | 571 kg | 571 kg | 571 kg | 571 kg | 571 kg | 571 kg |
| Recycled Aggregates | 222 kg | 449 kg | 498 kg | 555 kg | 610 kg | 665 kg |

(Table 3.9) Composition of materials for M60 Grade Concrete for various replacement percentages for $1m^3$

| Material in kg | Replacement Percentage | | | | | |
|---|---|---|---|---|---|---|
| w/c = 0.3 | 20% | 25% | 30% | 35% | 40% | 60% |
| Water | 175 | 175 | 175 | 175 | 175 | 175 |
| Cement | 585 | 585 | 585 | 585 | 585 | 585 |
| Coarse Aggregates | 865 | 809 | 756 | 702 | 648 | 432 |
| Fine Aggregates | 556 | 556 | 556 | 556 | 556 | 556 |
| Recycled Aggregates | 215 | 270 | 323 | 378 | 431 | 647 |

## 3.5 Zoning of Aggregates

(Table 3.10) Gradation for zoning of fine aggregates (ZONE II)

| Sieve Size | Retained (gm) | Cumulative Retained (gm) | Passing (gm) | % Passing |
|---|---|---|---|---|
| 10 mm | 0 | 0 | 1000 | 100 |
| 4.75 mm | 34.3 | 34.3 | 965.7 | 96.57 |
| 2.36 mm | 201.6 | 235.9 | 764.1 | 76.41 |
| 1.18 mm | 183.4 | 419.3 | 580.7 | 58.07 |
| 600 micron | 59.3 | 478.6 | 521.4 | 52.14 |
| 300 micron | 124.1 | 602.7 | 397.3 | 39.73 |
| 150 micron | 308.7 | 911.4 | 88.6 | 8.86 |

It might be reasonable to believe that the best gradation is one that produces the maximum density. This would involve a particle arrangement where smaller particles are packed between the larger particles, which reduces the void space between particles. This creates more particle-to-particle contact.

(Table 3.11) Standard Table of IS Code for Zoning using IS 383:1970

| IS Sieve | Percentage passing for | | | |
|---|---|---|---|---|
| | Grading Zone I | Grading Zone II | Grading Zone III | Grading Zone IV |
| 10mm | 100 | 100 | 100 | 100 |
| 4.75mm | 90 – 100 | 90 – 100 | 90 – 100 | 90 – 100 |
| 2.36mm | 60 – 95 | 75 – 100 | 85 – 100 | 95 – 100 |
| 1.18 mm | 30 – 70 | 55 – 90 | 75 – 100 | 90 – 100 |
| 600 micron | 15 – 34 | 35 – 59 | 60 – 79 | 80 – 100 |
| 300 microns | 5 – 20 | 8 – 30 | 12 – 40 | 15 – 50 |
| 150 microns | 0 – 10 | 0 – 10 | 0 – 10 | 0 – 15 |

Figure 3.2

Zoning of fine Aggregates

## 3.6 Aggregate Gradation

### 3.6.1 Gradation for Aggregates of 20mm

(Table 3.12) Gradation of 20 mm aggregates for well graded aggregate mix

| Sieve size | % Retained on each sieve | Cumulative % Retained | Cumulative % passing |
|---|---|---|---|
| | 20 mm | 20 mm CA | 20 mm CA |
| 20 mm | 16.75 | 16.75 | 83.25 |
| 10 mm | 53.98 | 70.73 | 29.27 |
| 4.75 mm | 28.43 | 99.16 | 0.84 |
| 2.36 mm | 0.84 | 100 | 0 |
| 1.18 mm | 0 | 100 | 0 |
| 600 um | 0 | 100 | 0 |
| 300 um | 0 | 100 | 0 |
| 150 um | 0 | 100 | 0 |
| Pan | 0 | 100 | 0 |

Maximum size of aggregate is often restricted by clear cover and minimum distance between the reinforcement bars. Maximum size of coarse aggregate should be 5 mm less than clear cover or minimum distance between the reinforcement bars, so that the aggregates can pass through the reinforcement in congested areas, to produce dense and homogenous concrete. It is advantageous to use greater maximum size of coarse aggregate for concrete grades up to M35 where mortar failure is predominant. Lower water/cement ratio will mean higher strength of mortar (which is the weakest link) and will result in higher strength of concrete. However, for concrete grades above M40, bond failure becomes predominant. Higher maximum size of aggregate, which will have lower area of contact with cement mortar paste, will fail earlier because of bond failure. Hence for higher grades of concrete (M40 and higher) it is advantageous to use lower maximum size of aggregate to prevent bond failure

### 3.6.2 Gradation of aggregates of 10mm

(Table 3.13) Gradation of 10mm aggregates for well graded aggregate mix

| Sieve size | % Retained on each sieve | Cumulative % Retained | Cumulative % passing |
|---|---|---|---|
| | 10 mm CA | 10 mm CA | 10 mm CA |
| 20 mm | 0 | 0 | 100 |
| 10 mm | 13.09 | 13.09 | 86.91 |
| 4.75 mm | 84.17 | 97.26 | 2.74 |
| 2.36 mm | 2.74 | 100 | 0 |
| 1.18 mm | 0 | 100 | 0 |
| 600 um | 0 | 100 | 0 |
| 300 um | 0 | 100 | 0 |
| 150 um | 0 | 100 | 0 |
| Pan | 0 | 100 | 0 |

In order to achieve better packing density, aggregates of nominal size 10mm were also used with the intention of filling voids created by usage of 20mm nominal size aggregates. 10mm nominal size aggregates helps in increasing the workability as well as helps in obtaining a well gradation. In this experimental programmes too 10mm and 20mm nominal size aggregates were used in equal quantities for the sake of obtaining both strength as well as good gradation.

### 3.6.3 Gradation of sand

(Table 3.14):-Th**e g**radation of sand for well graded concrete mix is given below

| Sieve size | % Retained on each sieve | Cumulative % Retained | Cumulative % passing |
|---|---|---|---|
| | Sand % | Sand % | Sand |
| 20 mm | 0 | 0 | 100 |
| 10 mm | 0 | 0 | 100 |
| 4.75 mm | 0 | 0 | 100 |
| 2.36 mm | 22.53 | 22.53 | 77.47 |
| 1.18 mm | 39.29 | 61.82 | 38.18 |
| 600 um | 3.88 | 65.7 | 34.3 |
| 300 um | 8.13 | 73.83 | 26.17 |
| 150 um | 20.24 | 94.07 | 5.93 |
| Pan | 5.97 | 100 | 0 |

As there are different types of sand, so we will have to judge that which type of sand is the best to be used. The sand is differentiated on the basis of its gradation. The sand will be called graded if it consists of particles having a variety of dimensions, such type of sand is recommended for use because this type of sand will posses the capability to form a compact structure thus will have more strength as compared to fine sand. The fine sand will also form compact structure but will increase the amount of water needed in concrete, which will decrease the strength of the concrete.

The fineness modulus of the sand is = (100 + 77.47 + 38.18 + 34.3 + 26.17 + 5.93)/100 = 2.82

(Table 3.15) Fineness Modulus range as per ASTM standards

| Type of Sand | Fineness Modulus Range |
|---|---|
| Fine Sand | 2.2 – 2.6 |
| Medium Sand | 2.6 – 2.9 |
| Coarse Sand | 2.9 – 3.2 |

### 3.6.4 Combined Aggregate Gradation

Aggregate percentage was varied to get the combined gradation curve which matches with the 0.45 power chart curve.

(Table 3.16) Gradation for combined aggregate used in M40 & M60 Mix Design

| Combined aggregate grading ( 33.33% of 20mm ; 33.33% of 10mm ; 33.33% of sand) | | | |
|---|---|---|---|
| Sieve Size | % Retained | cum % retained | cum % passing |
| 20mm | 0 | 0 | 100 |
| 10mm | 11.12 | 11.12 | 81.88 |
| 4.75mm | 30.94 | 42.06 | 57.94 |
| 2.36mm | 13.05 | 55.11 | 44.89 |
| 1.18mm | 22.75 | 77.86 | 22.14 |
| 0.6mm | 2.25 | 80.11 | 19.89 |
| 0.3mm | 4.71 | 84.82 | 15.18 |
| 0.15mm | 11.72 | 96.54 | 3.46 |
| pan | 3.46 | 100 | 0 |

(Table 3.17) Gradation for 0.45 Power Chart:

| 0.45 Power Chart Curve | Sieve opening (mm) | Sieve opening power 0.45 in mm |
|---|---|---|
| cum % passing | | |
| 100 | 20 | 3.85 |
| 73.20 | 10 | 2.81 |
| 52.37 | 4.75 | 2.01 |
| 38.22 | 2.36 | 1.47 |
| 27.98 | 1.18 | 1.07 |
| 20.64 | 0.6 | 0.79 |
| 15.11 | 0.3 | 0.58 |
| 11.06 | 0.15 | 0.42 |
| 0 | 0 | 0 |

The normal grading chart used in the concrete industry has the sieve sizes on the X-axis spaced to the logarithm of the sieve size. The 0.45 power chart has the sieves spaced to the 0.45 power of the actual sieve opening (not the nominal particle size) expressed in microns.

(Figure 3.3) M60 with 20% replacement

(Figure 3.4) M40 with 20% replacement

(Figure 3.5)

Compression Testing Machine

(Figure 3.6)

M40 grade concrete with 40%

(Figure 3.7)

M60 grade concrete with 25% Replacement

(Figure 3.8)

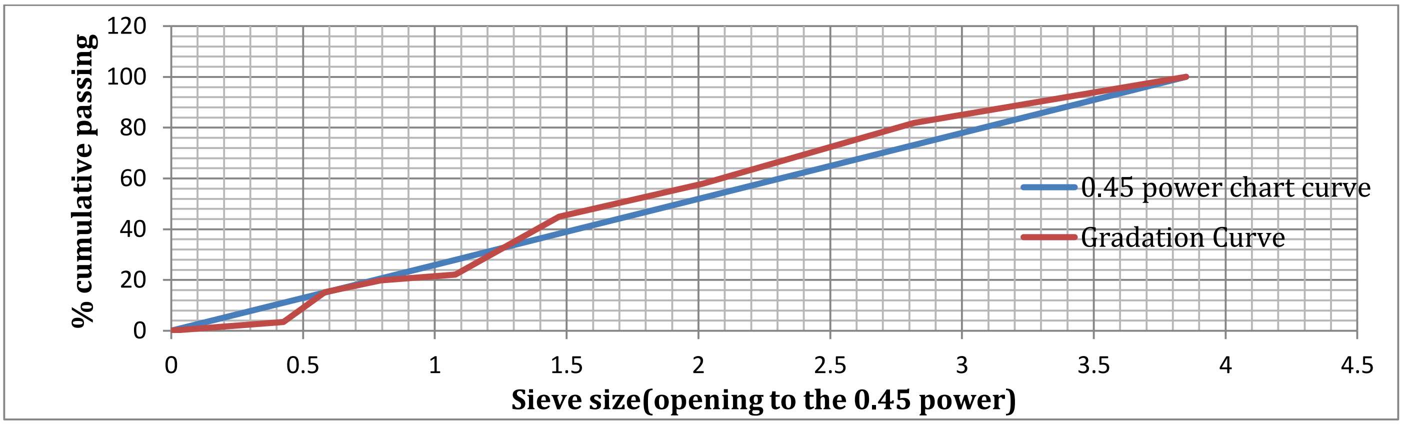
Compression Testing result for M40

# Chapter 4

# Results & Analysis

## 4.1 0.45 Power Chart

Power chart curve results in well graded aggregates so it was attempted to match the gradation with that of this curve changing the aggregate proportions in different trials. Finally 33.33% each of 20mm aggregates, 10mm aggregates and sand were used for well gradation.



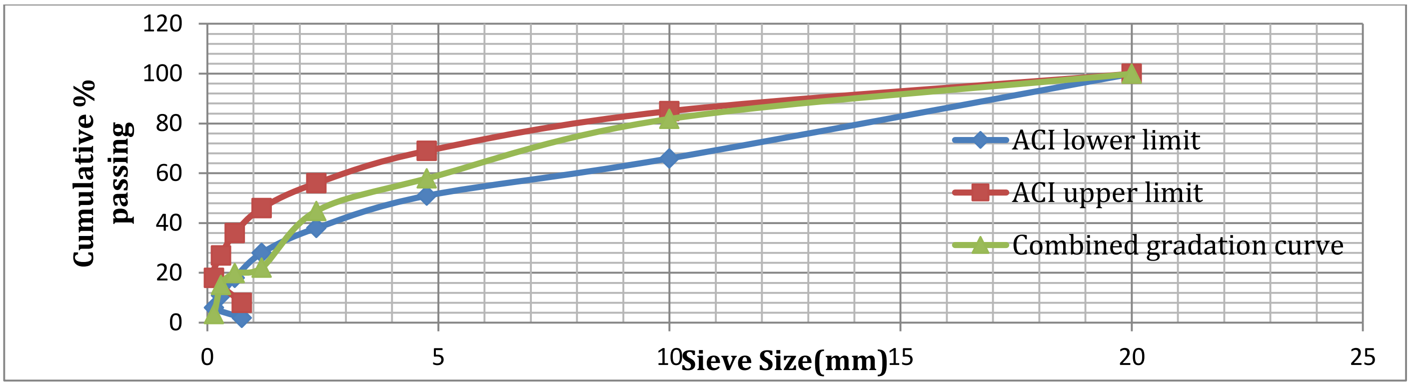

(Figure 4.1) 0.45 Power chart of Aggregates

## 4.2 ACI Limits

Checking the ACI Limits - Falling of gradation curve within ACI Limits ensures a check on the well gradation of aggregates. It acts as a cross checking technique to ensure better gradation.

(Table 4.1) ACI Limits

| Sieve Size (mm) | ACI lower limit | ACI upper limit |
|---|---|---|
| 20 | 100 | 100 |
| 10 | 66 | 85 |
| 4.75 | 51 | 69 |
| 2.36 | 38 | 56 |
| 1.18 | 28 | 46 |
| 0.6 | 18 | 36 |
| 0.3 | 11 | 27 |
| 0.15 | 6 | 18 |
| 0.75 | 2 | 8 |




(Figure 4.2) ACI Curve & Aggregate Gradation Curve

## 4.3 Factors Affecting Strength

**(1)** The recycled aggregates used have an average life of one year. The strength could be increased if recycled aggregates of 50 years average life is used.

**(2)** The abrasion value for the nominal aggregate used was 28.9 % making it usable for mix designs and for the recycled aggregates the value is much higher equal to 39.7%. However the abrasion test is recommended as it results in obtaining recycled aggregate free from mortar. Presence of mortar in recycled aggregate increases the water absorption and poor gradation.

**(3)** Usage of mechanical vibrator enhances the possibility of achieving high strength as compared to manual tamping. In this regard the cubes were compacted on a mechanical vibrator for a duration of approximately 5 to 10 minutes till the water film comes on the surface.

**(4)** The water cement ratio is maintained low to a value of 0.3 to 0.4 for the sake of obtaining maximum strength in 28 days. As the low environmental temperature creates a detrimental effect to cube strength.

**(5)** Recycled aggregates used were mechanically broken. However the strength of the concrete can be increased if recycled aggregates crushed from mechanical crushers are used.

**(6)** The slump value is small on account of low water cement ratio and delayed mixing time. However the care should be taken the mix design is not harsh as it leads to honeycombing.

**(7)** The recycled aggregates should be soaked for a duration of 24 hours before mixing to achieve surface saturated dry condition as its negligence will decrease the water content available to cement for hydration.

**(8)** The gradation of aggregates yielded the following results and ACI Limit curves as shown below:-

## 4.4 Compressive Strength of Mix Designs

**M40 Grade of concrete :-** Initially based upon the conclusions drawn on the basis of an extensive literature review the M40 grade concrete cubes were cast with 20%, 40%,60% which were further exacted to 45%, 50%,55% for more precise estimation of replacement of recycled aggregates and it was found that 50% replacement was the upper limit for aggregate replacement in M40 grade of concrete as evident from the tables given below:-

(Table 4.2) Strength of M40 Grade Concrete Mix Design

| **Replacement %** | **Days** | | |
|---|---|---|---|
| | **3 days** | **7 days** | **28 days** |
| **0%** | 21.23 N/mm$^2$ | 37.89 N/mm$^2$ | 54.22 N/mm$^2$ |
| **20%** | 19.86 N/mm$^2$ | 36.83 N/mm$^2$ | 50.76 N/mm$^2$ |
| **40%** | 15.91 N/mm$^2$ | 33.2 N/mm$^2$ | 49.67 N/mm$^2$ |
| **45%** | 13.96 N/mm$^2$ | 31.09 N/mm$^2$ | 49.55 N/mm$^2$ |
| **50%** | 13.92 N/mm$^2$ | 29.98 N/mm$^2$ | 48.89 N/mm$^2$ |
| **55%** | 13.71 N/mm$^2$ | 29.87 N/mm$^2$ | 46.04 N/mm$^2$ |
| **60%** | 13.66 N/mm$^2$ | 29.77 N/mm$^2$ | 44.86 N/mm$^2$ |

**M60 Grade of concrete:-** The same procedure as adopted in the above case is done for M60 only this time the replacement percentages change and initially varying from 20%,40%,60% ,we finally exacted to 25%,30%,35% in which 30% was found the upper limit for replacement as evident from the tables given below

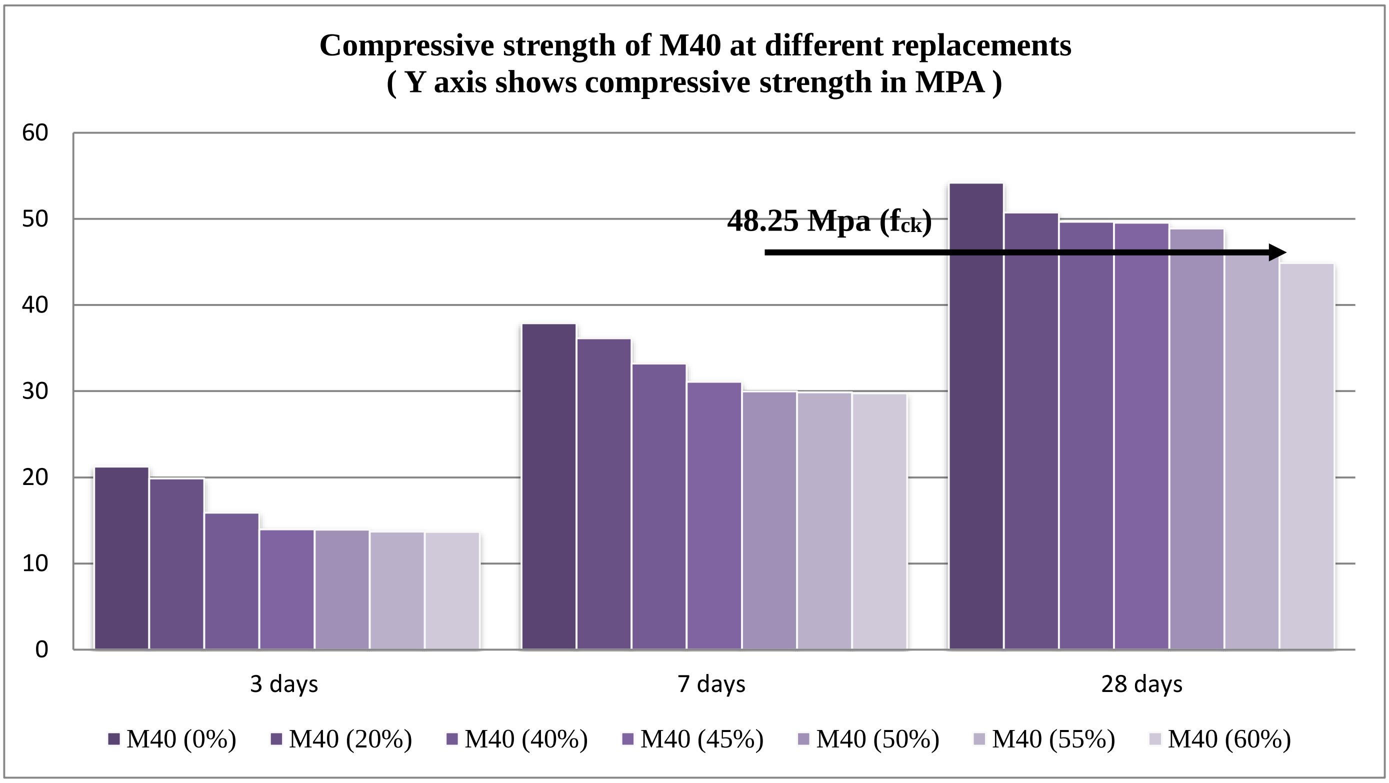
(Table 4.3) Strength of M60 Grade Concrete Mix Design

| **Replacement %** | **Days** | | |
|---|---|---|---|
| | **3 days** | **7 days** | **28 days** |
| **0%** | 30.60 N/mm$^2$ | 47.04 N/mm$^2$ | 74.99 N/mm$^2$ |
| **20%** | 29.91 N/mm$^2$ | 42.98 N/mm$^2$ | 71.23 N/mm$^2$ |
| **25%** | 28.17 N/mm$^2$ | 40.98 N/mm$^2$ | 70.70 N/mm$^2$ |
| **30%** | 27.14 N/mm$^2$ | 39.26 N/mm$^2$ | 69.14 N/mm$^2$ |
| **35%** | 25.13 N/mm$^2$ | 35.01 N/mm$^2$ | 67.88 N/mm$^2$ |
| **40%** | 26.42 N/mm$^2$ | 39.66 N/mm$^2$ | 67.92 N/mm$^2$ |
| **60%** | 21.54 N/mm$^2$ | 37.87 N/mm$^2$ | 63.98 N/mm$^2$ |

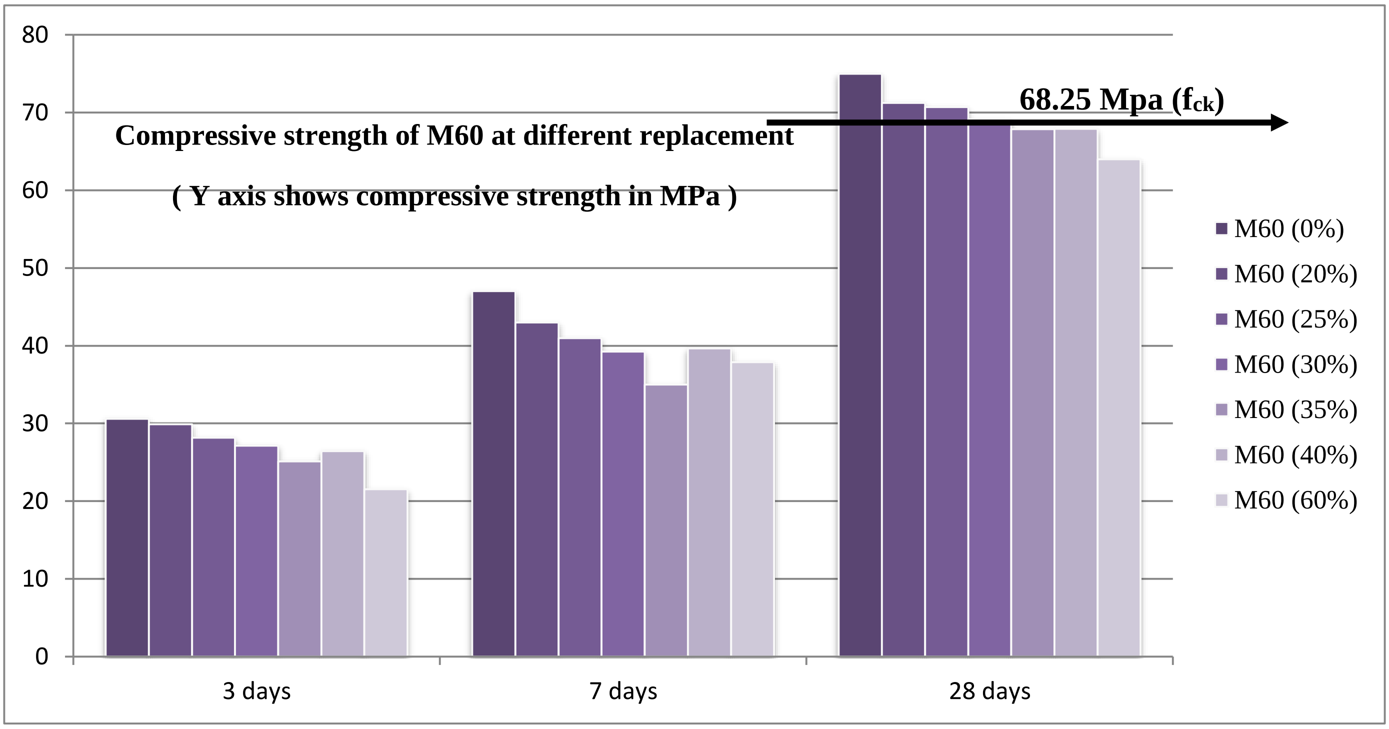
**(1)** In case of M40 grade concrete the replacement of aggregates by more than 50% fails to yield strength greater than target mean strength

**(2)** In case of M60 grade concrete the replacement of aggregates by more than 30% fails to yield strength greater than target mean strength.

.

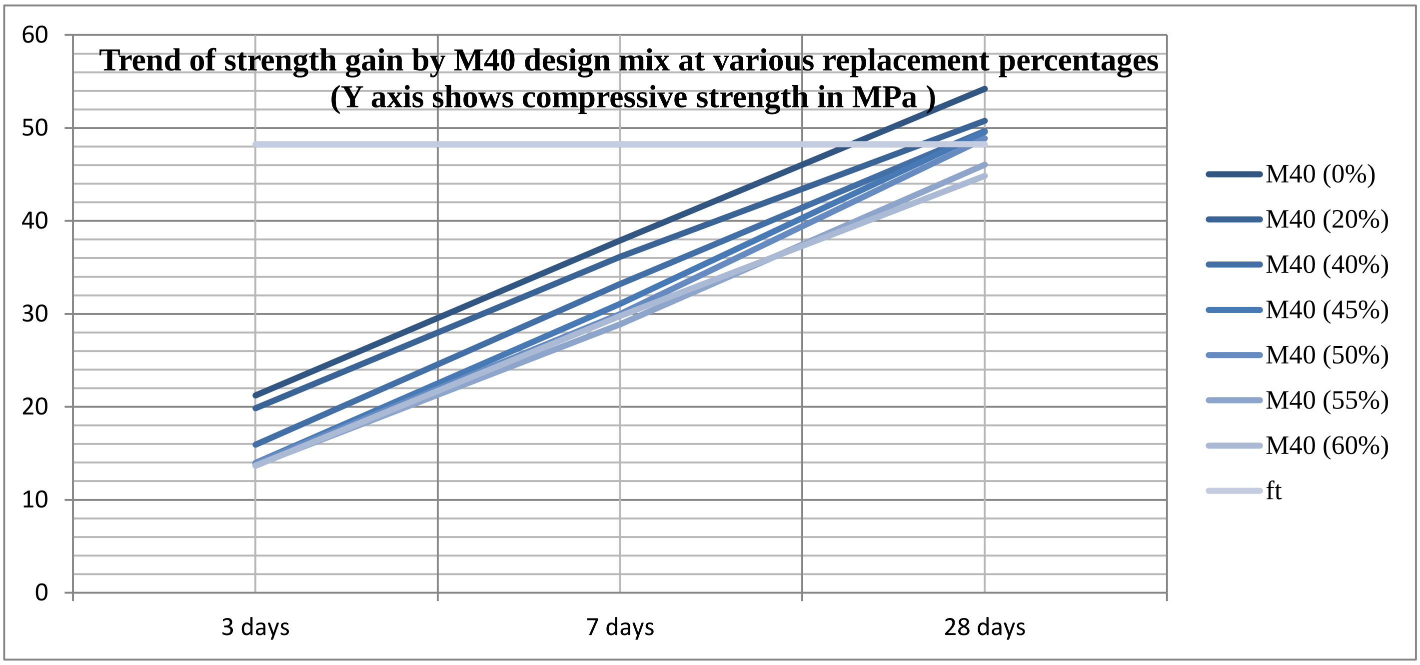



(Figure 4.3) Comparison of values of compressive strength for M40 (Y axis is compressive strength)

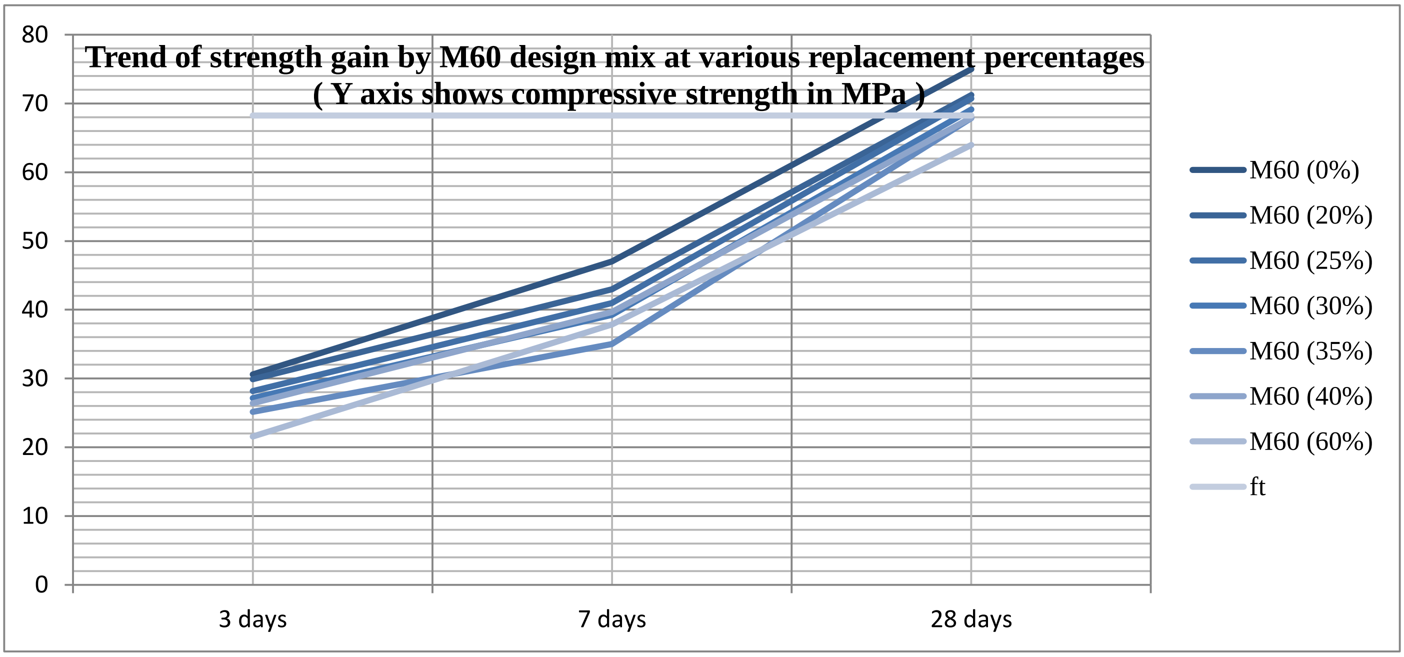



(Figure 4.4) Comparison of values of compressive strength for M60 (Y axis is compressive strength)

**(3)** The compressive strength of the cube decreases with increasing percentage of recycled aggregate. The replacement of aggregates by recycled aggregates leads to greater water absorption and increased porosity.




(Figure 4.5) Values of compressive strength for M40 & (Y axis is compressive strength)




(Figure 4.6) Values of compressive strength for M60 & (Y axis is compressive strength)

**(4)** Comparison of cost between RCA and Conventional Concrete considering only materials cost

(Table 4.4) Comparison of cost between RCA and Conventional Concrete for M40 at an optimal replacement of 50% of total coarse aggregates per $1m^3$

| Material | Unit | Quantity | Rate | Cost incurred in M40 Conventional Concrete | Cost incurred in M40 Recycled Aggregate Concrete |
|---|---|---|---|---|---|
| Cement | bags | 533 kg | 360/- per bag (50 kg) | 3,840/- | 3,840/- |
| Sand | kg | 571 kg | 820/- per $m^3$ | 1,76,686/- | 1,76,686/- |
| Virgin Aggregate | kg | 1110 kg | 1200/- per $m^3$ | 5,02,642/- | 2,51,320/- |
| Recycled Aggregate | kg | 555 kg | 200/- per $m^3$ | -NA- | 41,886/- |
| Total | | | | 6,83,168/- | 4,73,732/- |

(Table 4.5) Comparison of cost between RCA and Conventional Concrete for M60 at an optimal replacement of 30% of total coarse aggregates per $1m^3$

| Material | Unit | Quantity | Rate | Cost incurred in M40 Conventional Concrete | Cost incurred in M40 Recycled Aggregate Concrete |
|---|---|---|---|---|---|
| Cement | bags | 585.68 kg | 360/- per bag (50 kg) | 4,216.88/- | 4,216.88/- |
| Sand | kg | 556.05 kg | 820/- per $m^3$ | 1,72,060/- | 1,72,060/- |
| Virgin Aggregate | kg | 1513.08 kg | 1200/- per $m^3$ | 6,85,168/- | 4,79,617/- |
| Recycled Aggregate | kg | 323.95 kg | 200/- per $m^3$ | -NA- | 24,449/- |
| Total | | | | 8,61,444/- | 6,80,342/- |

**Targets Aimed**

- Workability Slump to be in the range of 100 to 150mm
- Exposure conditions to be kept strictly moderate
- Data of compressibility test to be taken strictly on the 3rd, 7th and 28th day.
- Strict conformity to

  **IS 8112 :** *For referring to properties of 43 Grade OPC.*

  **IS 10262:2009 :** *For referring to mix design methodology.*

  **IS 516 :** *For referring to compressive strength standards for concrete.*

  **IS 383:1970 :** *For referring to grading of fine aggregates.*

  **IS 2386 (Part IV) :** *For referring to crushing value and impact value of aggregates.*

Gradation of aggregates - The aggregates were chosen in such a manner that a well graded curve for aggregates is obtained. Well graded aggregates results in better packing density and higher strength. The closer the gradation curve from the 0.45 curve, better the strength and more well graded the aggregates.

# Chapter 5

# Conclusions and Future Scope

## 5.1 Conclusions

**(1)** The compressive strength of the concrete decreases with increasing replacement of coarse aggregate with recycled aggregate.

**(2)** It could be clearly suggested that M40 with replacement more than 50% will fail to obtain the desired target mean strength. Therefore the upper limit to replacement of coarse recycled aggregate with conventional aggregate can be set to 50%

**(3)** It could be understood that M60 with replacement of more than 30% will fail in compression test.

(Table 5.1) Suggested Replacements

| | |
|---|---|
| **M40** | **Up-to 50%** |
| **M60** | **Up-to 30%** |

**(4)** On comparing the total cost of M40 mix design for one meter cube of concrete with and without recycled aggregates we find **30.65%** of total cost savings when recycled aggregates were used.

**(5)** On comparing the total cost of M60 mix design for one meter cube of concrete with and without recycled aggregates we find **21.02%** of total cost savings when recycled aggregates were used.

## 5.2 Future Scope

The following points explain further work that can be done to investigate more deeply into this project and establish it on a more accurate scale:-

(1) Strengths corresponding to more optimum replacements between 50%- to -52% for M40 grade of concrete and between 30%-to- 35% for M60 grade of concrete.

(2) The aggregates used in experiments were from one year old Construction &Demolition Waste , however the procedure can be repeated for aggregates derived from older C&D Waste and the strengths can be compared to different ages of C&D waste.

# References

(1) Naik T R., *"**Sustainability of Concrete Construction**"*. Practice Periodical on Structural Design and Construction 13(2), 2008 pg 97-98

(2) Obla K, Kim H, and Lobo C, Crushed *"Returned **Concrete as Aggregates for New Concrete**"*, RMC REF Report: September 2007

(3) Osei D Y, ***"Compressive Strength of Concrete Using Recycled Concrete Aggregate as Complete Replacement of Natural Aggregate"***, Journal of Engineering, Computers & Applied Sciences (JEC&AS) ISSN No: 2319-5606 Volume 2, No.10, October 2013

(4) Sivakumar N, Muthukumar S, Sivakumar V, Gowtham D, Muthuraj V, ***"Experimental Studies on High Strength Concrete by using Recycled Coarse Aggregate"***, Research Inventy: International Journal of Engineering And Science Vol.4, Issue 01 (January 2014), PP 27-36

(5) Franklin S, Gumede M, ***"Studies on Strength and Related Properties of Concrete Incorporating Aggregates from Demolished Wastes: Part 1—A Global Perspective"***, Open Journal of Civil Engineering, 2014, 4, 311-317 Published Online December 2014

(6) Tushar R Sonawane , Sunil S Pimplikar, ***" Use of Recycled Aggregate Concrete"*** IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) ISSN: 2278-1684, PP: 52-59

(7) Martin Van, The construction Industry Challenges and Opportunities book: Uncertainty and Ground Conditions," **A Risk Management Approach**", Global Insight (2005)

(8) Holcim, Increase of resource efficiency and improving living conditions in developing and emerging countries – **A contribution of the cement and construction industry, Reuse and Recycling of Construction and Demolition Waste**, Oct 2007

(9)Keun-Hyeok Yang, Heon-Soo Chung, and Ashraf F. Ashour, **Influence of Type and replacement Level of Recycled Aggregate on concrete Properties**, ACI Materials Journal, V.105,No.3 June 2008

(10) Das,T.K., "**Development of Highways and Airports in India**," Proceedings of the 6th National Conference on Construction, 10-11 November 2003, New Delhi, CDROM, Technical Session 1, Paper No.7.