SUSTAINABLE CONCRETE PRODUCTION USING RECYCLED CONCRETE AGGREGATE BY COMPARISON OF COMPRESSIVE STRENGTH

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Abstract

This research is focused on recycling of aggregate obtained from demolition and waste produced in the construction industry. With the advent of industrial revolution, construction industry witnessed an exponential growth especially in the 20th century after the cursed events of world wars. The demand for the materials used in production of concrete endorsed an unprecedented demand which are all non-renewable resources and all play a vital role in sustaining all forms of life on earth.

The use of recycled concrete aggregate in our regular construction projects will not only reduce the strain on the production plants but also promise a brighter future for the human race.

The myths of lower quality and strength of recycled concrete aggregate are discussed in this thesis with comprehensive testing conducted on cylinders casted with different ratios of recycled concrete aggregate (RCA) on different days. The trends obtained are then discussed with different approaches and conclusions are made at the results obtained.

Cylinders of 4” diameter were used with 0, 10, 20, 30 and 40 percent replacement of RCA with virgin coarse aggregate and tests were conducted on 3, 7, 14 and 28 day after casting the cylinders. Afterwards the behavior of concrete with different ratios of RCA was analyzed thoroughly to make conclusions and recommendations for future based on the results. It was observed that the strength of concrete decreases proportionally with increase in percentage of RCA whereas the increase after 30% doesn’t follow the trend. We saw an abrupt change in behavior after crossing the value of 30% replacement by the recycled concrete aggregate.

Hence the use of recycled concrete aggregate (RCA) in the routine construction works will not only assure economic footprint but also boost sustainability and recycling in our industry. Still there is a lot of potential research to be conducted in this field especially in Pakistan where construction industry is still in its infancy and a lot of work is to be done in this topic.

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DEDICATION

This thesis we are dedicating to our parents and teachers without whom we could never have reached this stage of our lives.

Acknowledgments

Working on this project was not quite easy and we found it quite a tedious job especially at the start of the project when we were nowhere and felt frustrated about the start of the project. It was at this stage that we found immense pleasure in seeking advice from our project advisor Sir Mansoor Azam who motivated us and guided us at every step of the project. We would never have been able to complete this project without the supervision of Sir Mansoor and we are thankful to him from the core of our hearts.

We are also in dept of our co-advisor who always graced us with his presence whenever we were in trouble and gave due help to us everytime we walked into his office.

We extend our deep regards to our family and friends who helped and supported us every time we asked for their help and encouraged us the very moment we started feeling heart wrenching after failures during our project.

Finally we pray and pay thanks to our Almighty Allah Who gave us Hope, Guidance and Motivation at every point of our project and in every walk of life. Surely we’ll need His support further in our future to excel in every aspect of life.

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1 INTRODUCTION

1.1 GENERAL

We are witnessing the removal of non-renewable resources with an unprecedented pace. One may get shocked after knowing that concrete is the second most material used in the world with water at first place. Aggregate covers the maximum amount of space in concrete and gives strength to the structures which use concrete. Researchers suggest that we use more than 9 billion tons of aggregate annually and it is to be noted that it is a non-renewable resource which means we'll soon need another planet if we are unable to sustain our industry of construction and for this purpose there is a severe need of recycling in our daily lives. We civil engineers are pioneers of this green concept if we start using recycled materials in our daily practices and therefore in our research program, we have studied the behavior of recycled concrete aggregate and recommended its several uses. Our purpose is the enhancement and encouragement of use of recycled concrete aggregate in the construction industry of Pakistan.

1.1.1 RECYCLING

It is the process adopted to convert waste materials into reusable materials to prevent waste of materials which used, rave potential to be used, minimize the consumption of new raw materials ,use of energy , air pollution and water pollution (land filling). Recycling is an important component of modern techniques to reduce waste and is the third component of the waste hierarchy "Reduce, Reuse and Recycle"**.**

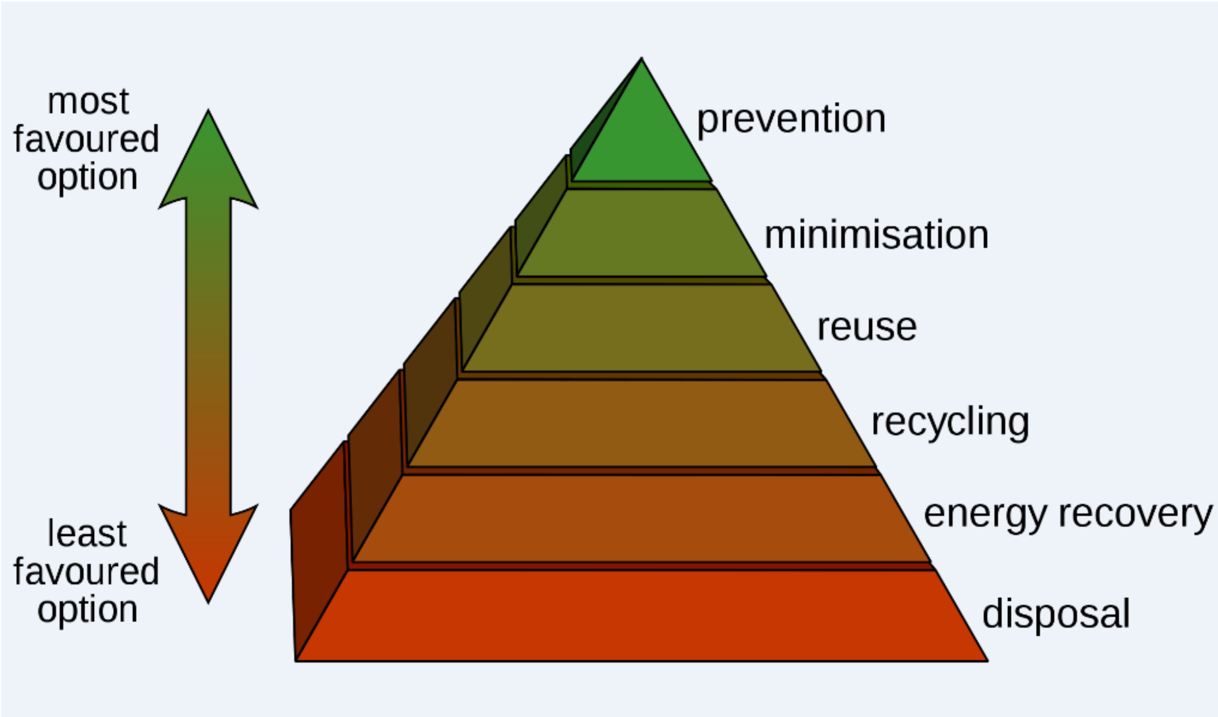

FIGURE 1-1

1.1.1.1 RECYCLING OF CONCRETE

Recycling of concrete is not a difficult process. It involves breaking of concrete, removing the steel, and crushing existing concrete into aggregate of required size and quality.

Most materials like plastic, paper wood and rubber are being recycled almost all over the world to protect the natural environment and natural resources. As concrete is the second mostly using material in the world and also a costly material therefore it must be recycled to recycled aggregate which can be used in recycled aggregate concrete for the construction purpose instead of being used as a landfill material. We can replace some amount of cement with some cementitious materials to produce sustainable concrete but the percent of cement is very less and it will not make much difference. As the concrete consists 80% of aggregate thus by replacing the natural aggregate with recycled aggregate will help to convert conventional concrete into sustainable concrete.

1.1.2 SUSTAINABILITY

Sustainability is to endure of the processes and systems and ensure sustainable development of any of the four domains i-e ecology, economics, political, culture. By achieving sustainability we can enable the earth to continue supporting the life of human beings.

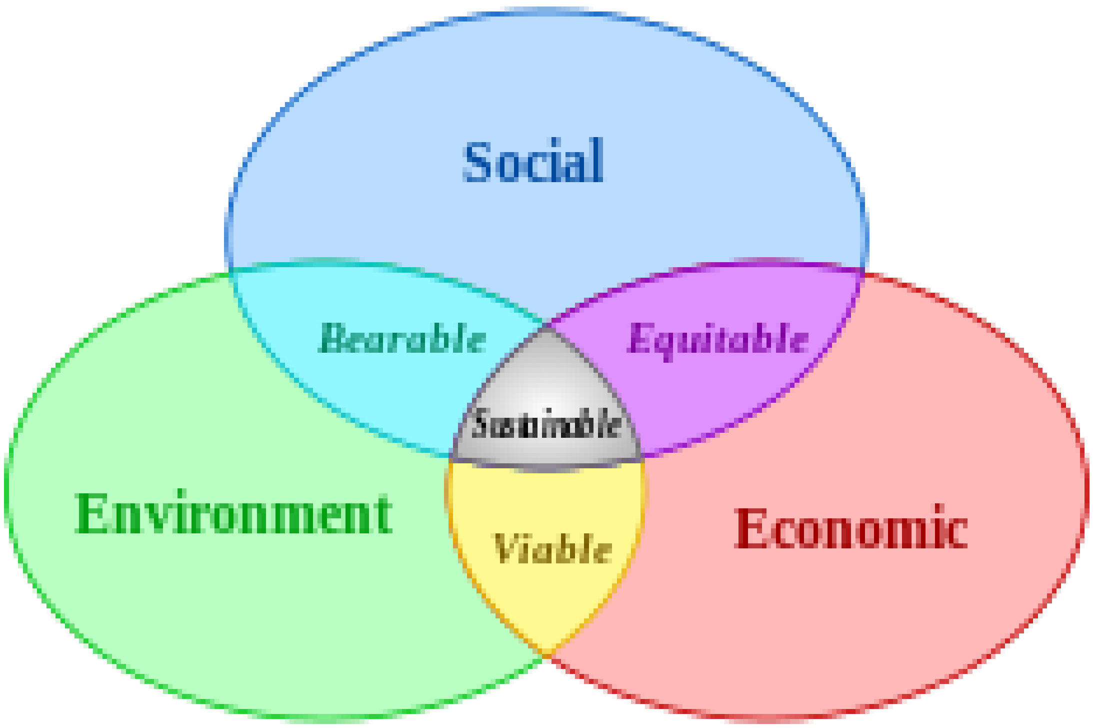

FIGURE 1-2

Sustainability can be attained in many ways using recycled concrete aggregate(RCA).The simplest answer to this notion is that the recycled aggregate which is just to be landfilled is recycled and is catered for some use. As space is an important factor in today's growing world population and depleting resources, landfill's space plays a key role in impacting human lives hence recycling the concrete aggregate reduces the economic impact of projects. However the use of recycled concrete aggregates (RCA) also reduces the need for natural aggregates in a great amount which may be replaced in a project upto 50%. Thus the recycling of concrete will decrease the environmental impact of the aggregate extraction and crushing process. The transportation requirements which induce a significant amount of cost in the project are also greatly lessened by reducing the needs of new material and disposal of waste material.
In addition to the resource management aspect, a large amount of carbon dioxide (CO_2) is also

consumed by recycled concrete aggregate which reduces the green house effect which is a most important topic now-a-days. This process is called carbonation. The natural process of carbonation occurs in all concrete from the surface inward. In the process of crushing concrete to create recycled concrete aggregates, the points where concrete is not yet carbonated to atmospheric carbon dioxide.

As compared to the natural aggregate concrete which is produce with the help of constituents i.e natural coarse and fine aggregates, cement and water we can use demolished or dump material which is a waste material of different structures of masonry and concrete in the preparation of recycled concrete aggregate. Instead of throwing the concrete as a waste material it can be reuse in structural concrete as recycled aggregate. The reuse of the concrete is mainly governed by the following factors.

- The availability of small dumping yard while we need large dumping yard for the disposing of concrete, and masonry of building.
- As the recycled aggregate have properties which is not good for concrete and thus the non-availability of recycled aggregate with proper properties and desire quality play an important role in discouraging the reuse of concrete.

Conventional aggregates are a non-renewable natural resource; by using recycled materials the natural deposits of conventional aggregates can be maintained. Therefore, by recycling construction rubble, these materials can be diverted from the landfill, thus reducing the amount of waste that is returned back to the earth. The use of recycled materials in roadway construction closely follows two of TNS principles by minimizing the extraction of natural resources and by avoiding the building of concentrations of unnatural materials.

It also reduces the air pollution caused by the process of obtaining natural aggregate from the mountains. During this process blasting is done in the mountains and after that crusher crushes the big boulders into aggregate of required sizes. During this whole process huge quantity of dust is produced which causes air pollution in surrounding areas and visibility is also reduced very much.

Construction and demolition waste makes up to 40% of total waste per year. Through recycling that waste, it can keep diminishing the resource of urban aggregates and natural aggregate can be used for high grade applications. In the future it may be useful to find new source of aggregate for the production of concrete due to increase in demand for and decrease in supply of natural aggregate.

1.1.3 BACKGROUND

With the extreme amount of destruction in the infrastructure in Europe apart from the loss of human life after World War 2, there was a much needed call for construction of new infrastructure .With this call came the two most challenging questions to the authorities. How the demand for material was to be filled at such a short notice and how did the demolished material was to be disposed off? Thus using recycling technique at that time saved both the raw material and space.Hence it became the foundation for the use of recycled material in construction and in future much of the research was conducted on providing sustainability to the concrete using recycled materials.

Many efforts and endeavors have been put forward in the past few years for the promotion of use of recycled concrete aggregate and also to implement rules and regulations, guidelines, and research studies to manage waste produced during construction and demolition. The primary objective is to encourage the use of recycled construction waste to contribute to the sustainable development of activities in the construction sector. It seems like a norm now to use recycled material in construction in many a countries especially the example of Netherlands is fair to put here, where recycled masonry and concrete is regularly used in roads as a base course.

The characteristics like physical quantity, its quality and the real cost of construction and demolition waste (CDW) are often underestimated. This cold behavior in turn leads to disposal of large quantities of recyclable materials, only to be replaced with similar conventional components. To reduce the ecological impact of the construction industry it is necessary to introduce beneficiation and recycling procedures to the CDW, especially when we have to use it in place of natural aggregates (NA).

The construction and demolition industry's key players still don't pay much heed to the use of selective demolition in their work and find it as less economic benefit with little value practically. Nevertheless, in the long term the use of recycled aggregate gives much more economic results as compared to conventional demolition approach which depends upon market prices of recovered materials, labor costs and tipping cost. Furthermore, if we examine the environmental benefits of using demolished material in projects like the space required to bury demolished material and the landfill and some other environmental impacts namely acidification, summer smog , climatic change, nitrification and amount of heavy metals atop the list.

A much greater form of sustainability can be achieved if the use of recycled concrete aggregate (RCA) is confirmed as a substitute of natural aggregate (NA) in the construction projects as it is considered one of the cleanest way to recycle construction and demolished way (CDW). This subject is witnessed a comprehensive scientific research and development projects over the last 40 years and many new variables like durability-related performance have been introduced leading the research into more much complex notions. But it must be remembered that

Pakistan is still in its incipient phase and the lack of infrastructure demands construction materials with a great amount hence it is the need of the hour to put our efforts in carrying research in this field of recycled construction materials.

1.1.4 OBJECTIVE

Objective of this study is to determine the compressive strength of the concrete produced by replacement of natural aggregate with recycled aggregate in different proportions which are 10, 20, 30 and 40%. Afterwards comparing those results with that of virgin aggregate concrete determining the difference between their strengths to find the trend of difference in strength as the replacement proportion is increased. At last producing an equation which will give the required mixed design for required strength and replacement.

1.1.5 SCOPES AND LIMITATIONS

- Replacement proportions of virgin aggregate with recycled aggregates are 0%, 10%, 20%, 30%, 40%.
- Source and grading of fine and coarse aggregate is kept constant.
- Water to cement ratio is also kept constant during studies i-e 0.57.
- Absorption capacity of recycled aggregate was found and more water was added in mix design accordingly.
- Primary sources of natural and recycled aggregate was same.
- Gradation of recycled aggregate was kept same as that of natural aggregate.
- Slump value taken for mix design was 3-4 inches but actual value for all batches came out to be zero.

CHAPTER 2

2 LITERATURE REVIEW

To get good quality concrete using recycled aggregate it is necessary to follow the minimum requirements defined by the BCSJ, RILEM, DIN 4226.100, and prEN13242:2002. Acceptable properties of course aggregate will set a base for concrete quality however proper mix design and concrete production methodology are also very important in concrete quality.

2.1 COMPOSITION

Recycled aggregate consists of natural virgin aggregate and adhered mortar. The physical properties of recycled aggregates depend both on adhered mortar quality and the amount of adhered mortar. The porosity of the mortar that is adhered to the RCA's surface depends upon the w/c ratio of the recycled concrete aggregate that is being used. The crushing process and the size of the recycled aggregate effects the quantity of adhered mortar.

The absorption capacity as well as the specific gravity of recycled aggregates is also a variable of the adhered mortar therefore it is very important to know the mortar's properties which is adhered to surface of RCA before using the RCA for required purpose if we want to control the properties of newly produced concrete. Cement mortar is responsible for worse of properties in recycled aggregates: lower density, and higher absorption, Los Angeles abrasion and sulfate content. These aggregate properties have a negative influence on recycled aggregate concrete quality, concrete properties which are duly dependent on strain (elasticity, shrinkage, and creep), also durability, and in a lesser extent strength. Aggregate properties can be improved by increasing the crushing processes in the crushing plant. It will diminishes the mortar attached but it will not be economical thus it's necessary to keep balance between crushing process and the quality required.

2.2 ABSORPTION CAPACITY

Absorption capacity of recycled aggregate increases due to the adhered mortar on it and it is the property which differentiates recycled aggregate from virgin aggregate, and it can have an influence both on structural properties of fresh and hardened concrete. After literature review we concluded that most researchers suggest only 30% replacement of natural course aggregate by recycled course aggregate for maintaining the absorption capacity of 5%. It means concrete made of course aggregate of more absorption capacity requires more water to give required workability.

Some researchers also concentrate on saturating the recycled aggregate before using it for required workability. If 100% of recycled concrete aggregate (RCA) is utilized using low w/c ratio its strength is higher as compared to natural aggregate concrete as water get absorbed and strength increases. If w/c ratio is same as for natural aggregate concrete the compressive strength of concrete made with recycled aggregate is lower as compared to natural aggregate concrete.

2.3 CREEP AND SHRINKAGE

All types of concrete shrinks even the shrinkage compensating concrete. Due to decrease in volume it can lead to development of cracks. Shrinkage also causes curling and wrapping which creates the variety of slab issues which also includes the reduction of load capacity. Shrinkage is the most important factor which effects the concrete performance so for improvement of the performance shrinkage should be studied and understood thoroughly. Creep and shrinkage are those factors which are also greatly affected by the use of recycled aggregate in concrete. Research studies show that by using the recycled concrete aggregate at or near SSD conditions, the mixtures are workable and have lower value of free shrinkage.

2.4 WORKABILITY

Workability is one of the concrete property which has its influence on strength, durability and also effects the labor cost because concrete with less workability is very difficult to handle during casting and pouring. **Concrete should be easy to place hand compact homogeneously** without bleeding and segregation. Concrete with less workability also shows honey combing and pockets after setting.

Workability in case of recycled aggregate concrete should be studied and understood carefully as it is reduced because of the shape of the aggregate particles and more absorption capacity due to adhered mortar. To get suitable workability more water should be added or the cement content is increased.

2.5 DURABILITY

Concrete's durability is its resistance against the actions of weathering, chemical attacks, abrasive actions and other degradation processes while maintaining its desired engineering properties. Concrete will be durable if hydrated cement paste structure is dense and the permeability is low, in very extreme weather conditions it has sufficient entertained air to resist freeze and thaw. Presence of impurities like sulfates, chlorides, silt and alkalis also effect greatly the durability of concrete.

Studies show that for recycled aggregate concrete durability is reduced to a great extent because it is less dense and hydrated cement paste is porous having more permeability as compared to conventional concrete.

2.6 PREVIOUS RESEARCHES

The properties and appropriate usage of recycled concrete aggregate as replacement of virgin aggregate are being studied for many years.

2.6.1 M Etxeberria (2006)

M Etxeberria (2006) studied the compressive strength of concrete produced by four different proportions of replacement of virgin aggregate with recycled aggregate that are 0%, 25%, 50% and 100%. He designed four different mix designs for each proportions to get the same compressive strength. He noted that workability of concretes were affected greatly as the quantity of recycled aggregate increases because absorption capacity of recycled aggregate increases. Workability of concrete is also affected by the texture and shape of aggregate and on the process of obtaining that aggregate. Aggregate obtained by impact crusher is of good quality and also we can obtain more aggregate by this process. He concluded that compressive strength of concrete produced by 100% replacement is very low and thus make it uneconomical. If we want to achieve the same strength then we have to increase the cement content which will also help to achieve sufficient workability. Concrete produced by 100% replacement will have the 20-25% less strength as compared to the concrete made by virgin aggregate.

2.6.2 Padmini A.K., (2009)

Padmini A.K., (2009) compared the properties of recycled aggregate concrete and the parent concrete from which the aggregate is obtained. He observed that method of crushing the parent concrete to obtain the aggregate, aggregate's shape and size and water cement ratio of the parent concrete has a significant effect on the properties of aggregate. Results of his study show that absorption capacity of aggregate increases if water cement ratio of parent concrete is reduced. Resistance of aggregate against the mechanical actions also reduce significantly and to get designed compressive strength water cement ratio should be reduced and cement content should be increased.

2.6.3 Khaldoun rahal (2007)

Khaldoun rahal (2007), He studied and compared the mechanical properties of RAC and NAC. He made ten mixes having target strength ranging from 20-50 MPA using natural and recycled aggregate. Tests were done for indirect shear strength and compressive strength after 1,3,7,14,28 and 56 days from the day of casting. The strains at maximum compressive stress and the modulus of elasticity tested by using concrete cylinders at 28 days were also reported. Compressive strength targets were achieved except of 40 and 50 MPA where strength was reduced. He also observed that strength for 56 days is 3% and 5% greater than that of 28 days for recycled aggregate concrete and natural aggregate concrete respectively.

2.6.4 Kiyoshi Eguchi (2007)

Kiyoshi Eguchi, (2007), studied on the production methods of RCA. In his research he studied on the properties like strength, workability, durability and fire resistance. Eventually, the environmental effects of the production method were evaluated and its suitability was confirmed. He concluded that emission of CO_2 was increased while replacing the aggregate with recycled one. According to the tests of mechanical properties they were affected as the compressive strength, elastic modulus and tensile strength were reduced if natural aggregate is removed by recycled aggregate. Positive aspects which he noted were that it is economical and has very less harming effects on environment.

2.6.5 Wengui li (2012)

Wengui li (2012), studied the strength, durability and the structural performance of concrete made by replacement of virgin aggregate by recycled aggregate for around 10 years (1996-2011). He compared those results with that of the concrete made by virgin aggregate. The results showed that the interfacial zone of aggregate – cement matrix in case of recycled aggregate concrete contained loose and porous hydrates. The mix design procedure was used the same as that in case of natural aggregate concrete. The mechanical properties such as compressive, tensile and shear strengths are lower than conventional concrete. Durability properties the carbonation and chloride penetration resistance were lower than conventional concrete. The factors such as shrinkage and creep were increased than that of conventional concrete.

2.6.6 Fonseca N. (2011)

Fonseca N. (2011), studied the effect of curing conditions. He also studied the mechanical properties of the concrete made by recycled aggregate and how it changes with curing condition. Results showed that when concrete is properly cured at a suitable temperature (10-15˚C) and humid environment, hydration products develop effectively, therefore hydrated cement paste becomes less porous and the concrete's density was increased. Results of compressive strength showed that it is generally insensitive to the conditions of curing but however splitting tensile strength decreased with the increase in the amount of recycled concrete aggregate. Elasticity modulus decreases with the increased use of recycled concrete aggregate.

2.6.7 Shi-Cong Kou (2013)

Shi-Cong Kou, (2013), made a research on a long term experimental results by replacing fly ash with cement proportional to recycled concrete aggregate. During the study, samples were cured in water or outdoor conditions for a long period of ten years. Results showed that for the concrete made by 100% replacement of virgin aggregate with recycled aggregate the compressive strength has the highest gain between 28 days and 5 years that is 60%. Conclusion of this study was that optimal mix is 50% replacement of aggregate and 25% replacement of cement with fly ash.

2.6.8 Ozgur Cakir (2014)

Ozgur Cakir,(2014), studied the mechanical properties of concrete while incorporating silica fume while making mix design for concrete. He produced four concrete mixes. In general, reduction of early age strength of concrete. It was concluded that mechanical properties of recycled aggregate concrete were even better as compared to virgin aggregate concrete up to 90 days.

2.7 CASE STUDY: O’Hare International Airport Modernization Project

RCA was used in the modernization of O’Hare Modernization Project (OMP). Test results showed that using recycled aggregate in the project reduced the bleeding and segregation while keeping the workability, compressive strength as same.

October 2009 faced a field test on the two lanes of Gate F7B. One of the lane was constructed using virgin aggregate whereas the adjacent lane was constructed using RCA and tests were conducted on both to check their performance. Concrete produced their onsite of airport was used as RCA. The ready mixed concrete supplier treated the RCA like lightweight aggregates and was able to produce concrete in a single-stage mixing process. The Contractors of the project hailed the use of recycled aggregate and complemented on the workability as well as well placement of RCA as fine as virgin aggregate concrete. The placement was in full service within four days.

Special sensors were required at the time of placement of concrete to measure the temperature, internal relative humidity, and the lift-off of the slab from the cement-treated permeable base. Some of the other properties were also observed, such as joint width and surface appearance. It had been deduced after five months of monitoring the two lanes of concrete with different properties that there was no difference in the behavior of both the lanes w.r.t different properties.

CHAPTER 3

3 Experimental program

This chapter will cover the following topics

1. The materials used in this project
2. Sources of the materials and their properties
3. ACI mix design procedure and mix design for this project

The specific gravity and absorption capacity of aggregate were calculated according to ASTM C127 standard test method. Similarly the absorption capacity of recycled aggregate was calculated according to the same ASTM C127. The concrete mix was designed under laboratory conditions having design strength of 4000 psi. The slump was tested at the time of casting which is approximately equal to zero. The compressive strength test was carried out according to the ASTM C39.

3.1 Materials

The materials used in the mix design and there specification are as follow.

3.1.1 Cement

Ordinary Portland cement (OPC) from ASKARI cement factory was used. The physical properties and chemical composition of cement is tabulated in the Table 3-1.

TABLE 3-1 CHEMICAL COMPOSITION OF (OPC)

Chemical name	Chemical formula	Shorthand natation	Weight percent
Tricalcium silicate	$3CaO.SiO_2$	C_3S	55
Dicalcium silicate	$2CaO.SiO_2$	C_2S	18
Tricalcium aluminate	$3CaO.Al_2O_3$	C_2A	10
Tetracalcium aluminoferrite	$4CaO.Al_2O_3.Fe2O_3$	C_4AF	8

Calcium sulfate dehydrate	$CaSO_4.2H_2O$	CSH_2	6
Gypsum			

3.1.2 Fine aggregate

The fine aggregate used in this project was taken from Lawrencepur. Sieve analysis was carried out according to the ASTM C136 standards. The absorption capacity and the specific gravity were calculated according to ASTM C128 standard

The results of specific gravity, absorption capacity are tabulated in the Table 3-2

TABLE 3-2 PROPERTIES OF FINE AGGREGATE

Properties	**Values**
Specific gravity	2.688
Absorption capacity	1.23%
Fineness modulus	2.48

The sieve analysis of fine aggregate was carried out for finding out the fineness modulus and the gradation is shown below in the Table 3-3.

TABLE 3-3 SIEVE ANALYSIS RESULTS OF FINE AGGREGATE

ASTM Sieve noin	**Opening (mm)**	**Mass Retained**	**Cumulative Mass Retained**	**% Retained**	**Cumulative % retained**	**% passed**
#4	4.75	9	9	0.90	0.90	99.10
#8	2.36	27	36	2.71	3.61	96.39
#16	1.18	66	102	6.61	10.22	89.78
#30	0.6	416	518	41.68	51.90	48.10
#50	0.3	384	902	38.48	90.38	9.62

#100	0.15	74	976	7.41	97.80	2.20
#200	0.075	18	994	1.80	99.60	0.40
PAN	0	4	998	0.40	100.00	0.00

The fineness modulus of the Lawrencepur sand was less which was about 2.02 so some of the fine particles were removed which passed sieve #100 and then the values was brought to 2.48. Three different samples were taken for sieve analysis and fineness modulus came out to be 2.54, 2.32 and 2.58. The average of these three values came out to be 2.48.

Fineness modulus =2.48

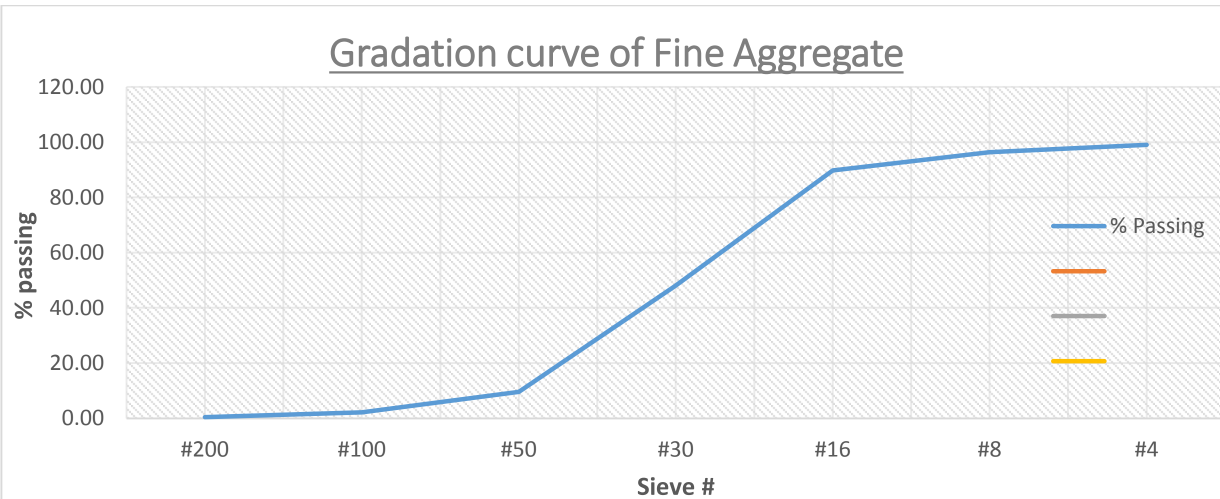

FIGURE 3-1 GRADATION CURVE OF FINE AGGREGATE

3.1.3 Coarse aggregate

Crushed stones from MARGALLA hills quarry of size ranging from 12mm to 25mm were used in this project. The physical properties of the coarse aggregate that is the specific gravity and the absorption capacity were calculated according to ASTM C128 and are shown below in the Table 3-4.

TABLE 3-4 PROPERTIES OF COARSE AGGREGATE

Properties	**Values**
Specific gravity (SSD)	2.57
Specific gravity (oven dried)	2.56

Apparent specific gravity	2.59
Absorption capacity	0.428%

The sieve analysis of course aggregate was carried out using ASTM C136 and the gradation is shown below in the Table 3-5.

TABLE 3-5 SIEVE ANALYSIS OF COARSE AGGREGATE

Sieve Size	Mass Retained	Cumulative Mass Retained	% Retained	Cumulative % Retained	% Passing
1”	0	0	0	0	100
¾”	618	618	12.41711875	12.41711875	87.58288125
½”	3254	3872	65.38075146	77.7978702	22.2021298
3/8”	620	4492	12.4573036	90.2551738	9.744826201
#4	473	4965	9.503717099	99.7588909	0.241109102
#10	12	4977	0.241109102	100	0

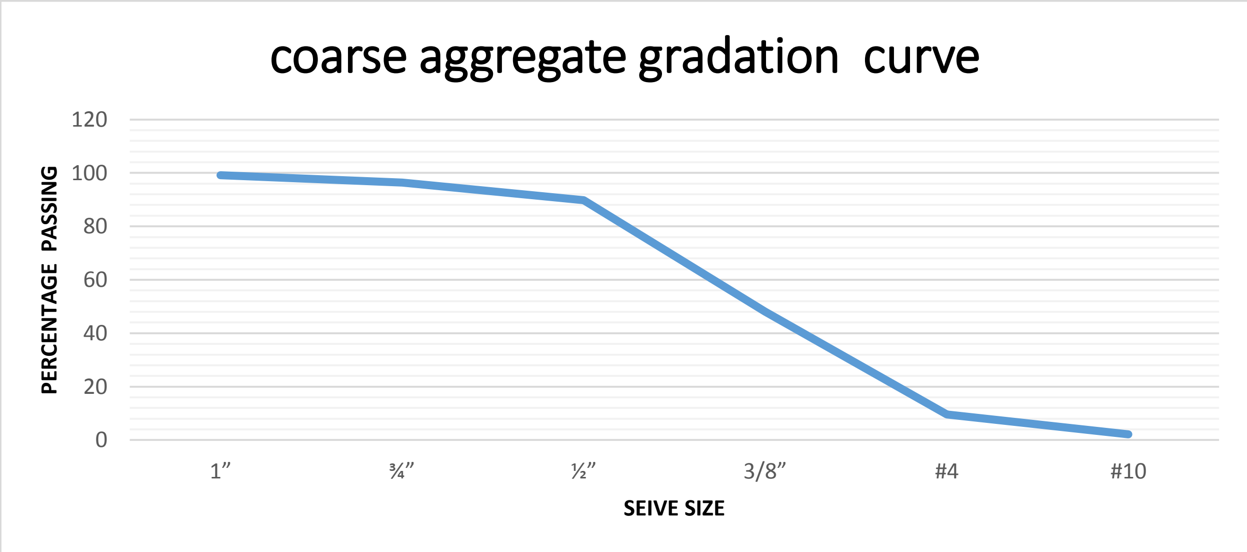

FIGURE 3-2 COARSE AGGREGATE GRADATION CURVE

3.1.4 Recycled Aggregate

3.1.4.1 Acquisition

Recycled aggregate was acquired from the tested beams lying outside the structural lab shed which were to be disposed off. The beams were crushed and the gradation was kept similar as that of virgin coarse aggregate which was carried out according to ASTM C136. The source of recycled aggregate is shown in the Figure 3-3 below. The mix design was same as that of virgin aggregate which was for 4000 psi strength.

FIGURE 3-3 SOURCE OF RECYCLED AGGREGATE

3.1.4.2 Properties

The absorption capacity of recycled aggregate is always higher than that of virgin aggregate, in our case it was greater by an amount of 5.312%. The recycled aggregate has a higher value of absorption capacity due to the slurry at the surface of the aggregate which is more porous and can attain water at saturation.

The specific gravity was also calculated according to the ASTM C128. The results obtained shows that the recycled aggregate has lesser specific gravity compared to virgin aggregate due to the reason of the slurry attached to the aggregate surface which increased the volume of the aggregate resulting in low density. The comparison of virgin and recycled aggregate in term of specific gravity and absorption capacity is listed below in Table 3-6.

TABLE 3-6 COMPARISON OF PROPERTIES OF NATURAL AND RECYCLED AGGREGATE

Properties	Natural Aggregate	Recycled Aggregate
Bulk specific gravity (oven dried)	2.56	2.13
Bulk specific gravity (SSD)	2.57	2.25
Apparent specific gravity	2.59	2.42
Absorption capacity	0.428%	5.74%

3.1.5 Water

Drinking quality water was used for the whole project, which is the requirement for a good concrete.

3.2 MIX DESIGN

The most common method used in North America is that established by ACI Recommended practice 211.1. Concrete mix design is obtain through a process which consists of a number of steps. In these steps suitable ingredients of concrete are selected and their relative amounts are determined with the objective of producing a concrete of the required, strength, durability, and workability as economically as possible.

Water cement ratio theory states that for a given combination of materials as long as workable consistency is obtained, the strength at a given age of concrete depends upon the w/c ratio.

As the w/c ratio decreases, the concrete strength increases. But the w/c ratio must not decrease 0.27 because it gives the minimum range of water which is required for the complete hydration of cement.

The economy depends upon the proportion of aggregate percentage present that would still give a workable mix.

The aim of designer would be to get concrete mixture of optimum strength and minimum concrete content which would result in the economy of concrete as cement is the most expensive ingredient of the concrete mix as well as acceptable workability of concrete.

The standard ACI mix design procedure consists of the following steps

3.2.1 Step 1. Data required

The data required in the calculation of proper proportions of different materials of concrete by ACI mix design are given below.

- Sieve analysis of course aggregate
- Sieve analysis of fine aggregate
- Unit weight of coarse aggregate
- Bulk specific gravities of coarse and fine aggregates
- Absorption capacities of coarse and fine aggregates
- Type of structural member to be cast
- Dimensions of structural member to be cast
- Minimum space between re-bars
- Required concrete strength
- Exposure conditions

The required data are given below

3.2.1.1 FINE AGGEGGATE

Fineness modulus= 2.48

Absorption capacity = 1.23%

Specific gravity = 2.688

3.2.1.2 COARSE AGGREAGTE

Specific gravity =2.57

Absorption capacity= 0.428%

3.2.2 Step 2. Choice of slump

If the slump is not specified then according to the job conditions an appropriate value can be selected from the Table 3-7.

TABLE 3-7 SLUMP VALUES FOR DIFFERENT TYPE OF CONSTRUCTION

Concrete Construction	Slump In Mm (Inch)	
	Maximum	Minimum
Reinforced foundation walls and footings	75 (3)	25 (1)
Plain footings, caissons and substructure walls	75 (3)	25 (1)
Beams and reinforced walls	100 (4)	25 (1)
Building columns	100 (4)	25 (1)
Pavements and slabs	75 (3)	25 (1)
Mass concrete	75 (3)	25 (1)

For our project we selected slump value as 3-4 in.

3.2.3 Step 3. Maximum Aggregate Size:

Generally, the largest maximum size of aggregates available

- For reinforced concrete maximum size may not exceed one-fifths (1/5) of the minimum dimensions between forms.
- Three-fourths (3/5) of minimum spacing between rebar or between steel and formwork
- For slabs the maximum size may not exceed one-thirds (1/3) of the slab depth.

The maximum aggregate size in selected in our project was 19 mm. and the sieve analysis of the coarse aggregate is given in the Table 3-5 above.

3.2.4 Step 4. Estimation of mixing water and air content:

On the basis of exposure conditions the concrete are of two types i.e. air entrained and non-air entrained. The air entrained is designed for harsh weather conditions. It may be exposed to sea water which contain different salts or may be exposed to freeze and thaw. The non-air-entrained is normal concrete which is exposed to normal weather conditions. The water and air content in both the cases can be taken from the following Table 3-8.

TABLE 3-8 WATER CONTENT IN NON-AIR-ENTRAINED CONCRETE

Slump in	Water, pound per cubic yard of concrete, for indicated sizes of aggregate							
	3/8 in	½ in	¾ in	1 in	1 ½ in	2 in	3 in	6 in
	Non-air-entrained concrete							
1 to 2	350	335	315	300	275	260	220	190
3 to 4	385	365	340	325	300	285	245	210
6 to 7	410	385	350	340	315	300	270	----
	3	2.5	2	1.5	1	0.5	0.3	0.2

The concrete in our project was non-air entrained and the mixing water came out to be 340lb/yd^3

3.2.5 Step 5. Water/Cement Ratio:

The water to cement ratio is related with durability and strength. As the w/c ratio decreases the durability increases. Water to cement ratio is selection is based on required strength and concrete type.

The following Table 3-9 shows the relationship between the 28th day compressive strength and the water to cement ratio.

TABLE 3-9 RELATION BETWEEN COMPRESSIVE STRENGTH AND W/C RATIO

Compressive Strength At 28th Day, (Psi)	Water To Cementitious Materials Ratio By Mass	
	Non-Air-Entrained Concrete	Air-Entrained Concrete
7000	0.33	----
6000	0.41	0.32
5000	0.48	0.40
4000	0.57	0.48
3000	0.68	0.59
2000	0.82	0.74

3.2.6 Step 6. Cement Quantity:

Cement content is calculated on the basis of water cement ratio and the water content.

Weight of Cement= weight of water content (Table 3-8) / the recommended water-to-cement ratio (Table 3-9).

The cement content for our project came out to be 596.5lb/yd^3.

3.2.7 Step 7. Estimation of Coarse Aggregate Content:

For a given maximum size of coarse aggregate and fineness modulus of fine aggregate, the percent of coarse aggregate in the concrete is given in the Table 3-10 below.

To get the required weight of coarse aggregate per cubic foot of concrete, the value from the table is multiplied with unit weight of coarse aggregate.

TABLE 3-10 PERCENT OF COARSE AGGREGATE IN TOTAL CONCRETE

	Fineness Modulus						
Max Aggregate (in)	2.4	2.5	2.6	2.7	2.8	2.9	3
0.375	0.5.	0.49	0.48	0.47	0.46	0.45	0.44
0.500	0.59	0.58	0.57	0.56	0.55	0.54	0.53
0.750	0.66	0.65	0.64	0.63	0.62	0.61	0.60
1.000	0.71	0.70	0.69	0.68	0.67	0.66	0.65
1.500	0.75	0.74	0.73	0.72	0.71	0.70	0.69
2.000	0.78	0.77	0.76	0.75	0.74	0.73	0.72
3.000	0.82	0.81	0.80	0.79	0.78	0.77	0.76
6.000	0.87	0.86	0.85	0.84	0.83	0.82	0.81

3.2.8 Step 8. Estimation of Fine Aggregate Content:

There are two standard methods to establish the fine aggregate content, the mass method and the volume method. We will use the "volume" method.

The volume of fine aggregate is found by subtracting the volume of coarse aggregate, cement and water from the total volume of concrete. And then this volume of fine aggregate is converted into its weight by multiplying it with specific gravity of fine aggregate.

The weight of fine aggregate in our max design came out to be 1307 lb/yd^3.

3.2.9 Step 9. Adjustment of moisture in the Aggregates:

As at site the aggregate may contain different amount of moisture. Therefore the moisture content of aggregate both fine and coarse are calculated and then it is adjusted. For example if the moisture content at the site is greater than the SSD condition then mixing water which must be added to the concrete during casting must be lessened. But if the moisture content in aggregate at site is less than the SSD condition then the mixing water must be increased by that amount.

3.3 CONCRETE MIX PROPORTIONS

Mix design calculations were carried out for a non air entrained 4000 psi mix design concrete, which corresponded to w/c ratio of 0.57.The estimated batch weights (pounds per cubic yard) are given below in the Table 3-11.

TABLE 3-11 CONCRETE MIX PROPORTION

Serial no	**Material**	**Unit weight (lb/yd^3)**
1	Water	340
2	Cement	596.5
3	Fine aggregate	1307
4	Coarse aggregate	1635

Weight of concrete = 3837.5 lbs/yd^3

3.4 CASTING

Casting cylinder dimensions 4”x8”

TABLE 3-12 TEST DAYS AND NO OF CYLINDERS

Serial No	Replacement (%)	Test Conducting Days	No Of Cylinders
1	0	3,7,14,28	12
2	10	3,7,14,28	12
3	20	3,7,14,28	12
4	30	3,7,14,28	12
5	40	3,7,14,28	12

For each test conducting day 3 cylinders were tested and the average value was taken.

Total cylinders = 60

3.5 COMPRESSION TESTING MACHINE:

Any suitable testing machine may be used for testing. Two hardened bearing blocks are used, one as a seat of specimen and other will bear the upper surface. There blocks should be plane and follow all the specifications of ASTM C39. Compression tests can be undertaken as a part of design process. Structural codes are mainly defined by compressive strength. The tests are easy and relatively economical to carry out.

Specimen is loaded with a control rate of 0.25 MPa/sec. loading is done until failure of specimen occurs, which is the maximum load a specimen can carry. Higher the rate of the loading higher will be the strength; lower strength in case of slow rate of loading may be due to the cracks propagation and strain due to creep. The compression is purely uniaxial

Three cylinders were tested and then the average value was taken.

CHAPTER 4

4 Experimental results

This chapter will cover the following topics

1. Amount if different materials in different batches with different percent of replacement
2. Mixing of concrete
3. Casting of concrete
4. Curing of concrete
5. Testing and testing results of concrete at different stages.

4.1 Batches

Batching is the "process of weighing the ingredients or taking the ingredients in volumetric measures and introducing into the mixer the ingredients for a batch of concrete".

Five different types of batches were casted with different percentages of recycled aggregate. `

4.1.1 Batch 1

First one is 0 % replacement of natural aggregate with recycled aggregate. The weightages of concrete constituents with zero percent replacement are given in the Table 4-1 below.

TABLE 4-1 CONSTITUENT'S AMOUNTS IN CONCRETE WITHOUT REPLACEMENT

Materials	**Amount In Kg**
Coarse Aggregate	25.56
Sand	17.06
Cement	8.53
Water	4.862

4.1.2 Batch 2

In batch 2, 10 % of natural aggregate was replaced by recycled aggregate. As the absorption capacity of recycled aggregate is greater than that of natural aggregate therefore extra amount was to be added to bring recycled aggregate to SSD state. The extra amount of water for bringing recycled aggregate into SSD state is 0.195kg. The weightages of concrete constituents with 10 % replacement are given in the Table 4-2 below.

TABLE 4-2 CONSTITUENT'S AMOUNT IN CONCRETE WITH 10% REPLACEMENT

Materials	Amount In Kg
Coarse Aggregate	30.672
Recycled Coarse Aggregate	3.4
Sand	22.74
Cement	11.37
Water	6.675

4.1.3 Batch 3

In batch 3, 20 % of natural aggregate was replaced by recycled aggregate. The extra amount of water for bringing recycled aggregate into SSD state is 0.4kg. The weightages of concrete constituents with 20 % replacement are given in the Table 4-3 below.

TABLE 4-3 CONSTITUENT'S AMOUNT IN CONCRETE WITH 20 % REPLACEMENT

Materials	Amount In Kg
Coarse Aggregate	27.272
Recycled Coarse Aggregate	6.8
Sand	22.74
Cement	11.37
Water	6.88

4.1.4 Batch 4

In batch 4, 30 % of natural aggregate was replaced by recycled aggregate. The extra amount of water for bringing recycled aggregate into SSD state is 0.0.586kg. The weightages of concrete constituents with 30 % replacement are given in the Table 4-4 below.

TABLE 4-4 CONSTITUENT'S AMOUNT IN CONCRETE WITH 30% REPLACEMENT

Materials	Amount In Kg
Coarse Aggregate	23.872
Recycled Coarse Aggregate	10.2
Sand	22.74
Cement	11.37

4.1.5 Batch 5

In batch 5, 40 % of natural aggregate was replaced by recycled aggregate. The extra amount of water for bringing recycled aggregate into SSD state is 0.781kg. The weightages of concrete constituents with 40 % replacement are given in the Table 4-5 below.

TABLE 4-5 CONSTITUENT'S AMOUNT IN CONCRETE WITH 40% REPLACEMENT

Materials	Amount In Kg
Coarse Aggregate	20.472
Recycled Coarse Aggregate	13.6
Sand	22.74
Cement	11.37
Water	7.261

4.2 MIXING

The successful placement of concrete is dependent upon careful mixing, the proper equipment, and adequate transportation. Mixing concrete is simply defined as the "complete blending of the materials which are required for the production of a homogeneous concrete". There are many components of mixing on which the achievement of uniform concrete mixture depends. They must be consider while mixing the ingredients to form concrete and they are given below.

- Location,
- shape
- angle of the mixing blades
- shape of the mixing chamber
- speed of rotation
- Horsepower.

It should be kept in mind that all the batches must be mixed consistently as given in the design specifications so that the final strength of concrete is not compromised.

The different constituents of concrete are charged into a concrete mixer and then the water is added moderately. Charging is an important step because it gives the materials an opportunity to pre-blend. Then mix the concrete for about 3-5 minutes; until a uniform, workable consistency is achieved. The mixing should be in the range because mixing beyond the range reduces the workability. The mixer was running and concrete was dumped into a wheelbarrow for transporting to casting area. The mixing time is also dependent upon the volume of concrete to be mixed.

FIGURE 4-1 CONCRETE MIXER

4.3 CASTING

Test cylinders ASTM C31 are cast to verify the specified compressive strength of the mix has been achieved. A 6-inch-diameter by 12-inch-tall steel molds is used.

The 6-inch diameter molds were filled in three equal layers, rodding each layer 25 times. After rodding each layer, tap the outside of the mold to remove any remaining air voids but shouldn't be tapped too much which could result in segregation. Once the mold is filled, make the top layer plane with the help of trowel for clear finishing.

4.4 CURING

Curing of concrete must be done to ensure the strength development and durability of concrete. Curing maintain the desired moisture and temperature conditions, both at depth and near the surface, for extended periods of time. Properly cured concrete has an enough amount of moisture for continued hydration and strength's development, stability of volume of concrete, and resistance to freezing and thawing.

Proper curing temperatures must be maintained during the curing of concrete otherwise the hydration reaction of cement will be affected. If the concrete is too hot, the hydration reaction will be too rapid for a proper crystal growth. Thus, concrete will not attain proper strength. The reaction being exothermic, temperature differentials will be created within the concrete that may cause cracks. Unsuitable hydration on the concrete surface may produce rough surface and a porous concrete structure. Such permeable concrete structures will permit calcium hydroxide to contact the concrete surface causing efflorescence. The concrete structure is also weakened. Other important aspects that need care during the curing are proper humidity, circulation, insulation, and time control.

The molds were opened after 24 hours so that they have gained enough strength to hold their shape or in other words they have reached their final setting time, then the cylinders were kept in the curing box until it is picked up and brought to a lab at the day of testing. Twelve cylinders were casted for each type of coarse aggregate percentage replacement. At days 3,7,14 and 28 each respective day three cylinders were tested and the average value was taken.

FIGURE 4-2 CURING OF CONCRETE CYLINDERS

4.5 COMPRESSION TESTING MACHINE:

Any suitable testing machine may be used for testing. Two hardened bearing blocks are used, one as a seat of specimen and other will bear the upper surface. There blocks should be plane and follow all the specifications of ASTM C39. Compression tests can be undertaken as a part of design process. Structural codes are mainly defined by compressive strength. The tests are easy and relatively economical to carry out.

Specimen is loaded with a control rate of 0.25 Mpa/sec. loading is done until failure of specimen occurs, which is the maximum load a specimen can carry. Higher the rate of the loading higher will be the strength; lower strength in case of slow rate of loading may be due to the cracks propagation and strain due to creep. The compression is purely uniaxial

Three cylinders were tested and then the average value were taken.

FIGURE 4-3 TESTING MACHINE

4.6 Testing

Testing were done only for the compressive strength of concrete of all the batches at 3rd , 7th 14th and 28th day. The machine used were stress controlled which give only pre peak valve of graph of strength. Some of sample tested are shown in the following Figure 4-4.

FIGURE 4-4 TESTED SAMPLES

4.6.1 Compressive strength:

Compressive strength is the property of a material or structure to withstand loads having a tendency to diminish size or crush it, rather than tensile strength, which withstands loads having a tendency to stretch or elongate. In other words compressive strength resists force of compression.

Compression tests can be undertaken as a part of design process. Structural codes are mainly defined by compressive strength. The tests are easy and relatively economical to carry out.

Factors affecting the compressive strength:

- Quantity of water
- w/c ratio
- Type of ingredients(mostly aggregate)
- mix proportions
- Curing
- Age
- Size and shape off specimen

- Test conditions

It is the mixing, handling and batching of a concrete that will define a good and bad concrete.

4.6.1.1 Compressive test of concrete without replacement

The compressive strength of concrete made with using natural aggregate at different stages are given in the Table 4-6 below.

TABLE 4-6 COMPRESSIVE STRENGTH OF CONCRETE WITHOUT REPLACEMENT

0% replacement	strength=	strength (psi)
3	15.2333333	2208.833329
7	19.833333	2875.833285
14	23.133333	3354.333285
28	28.633333	4151.833285

The graph between the number of day and the compressive strength in Psi is given below in the Figure 4-5.

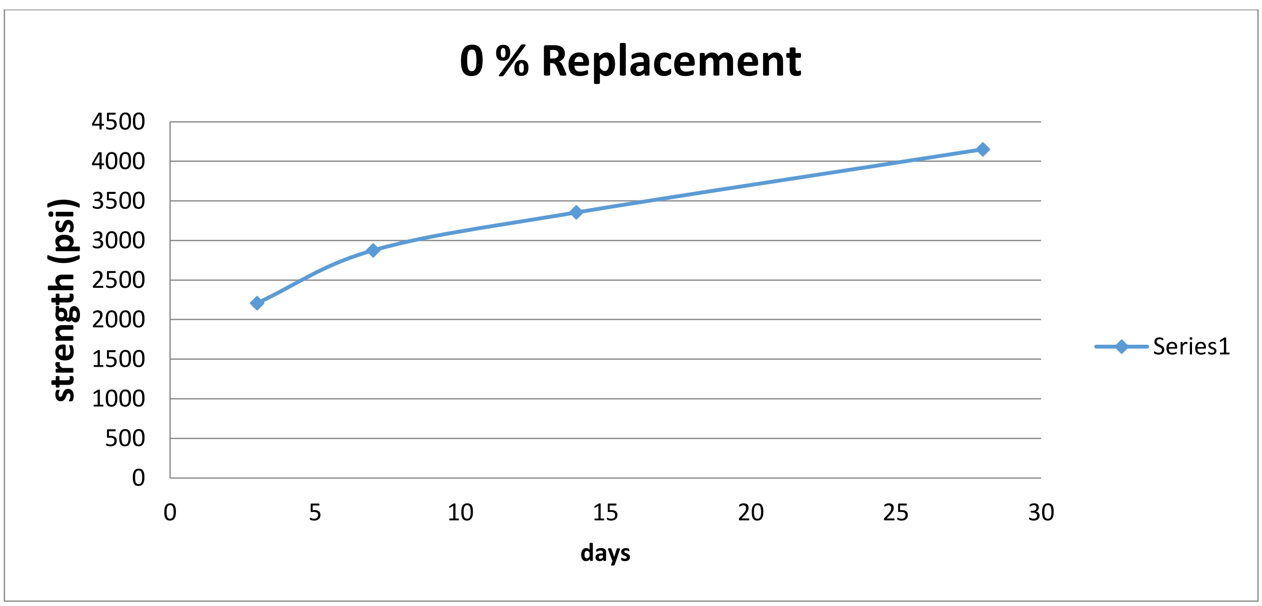

FIGURE 4-5 STRENGTH GRAPH WITHOUT REPLACEMENT

4.6.1.2 Compressive test of concrete with 10% replacement

The compressive strength of concrete made with using natural aggregate at different stages are given in the Table 4-7below.

TABLE 4-7 COMPRESSIVE STRENGTH OF CONCRETE WITH 10% REPLACEMENT

10% replacement	strength	Strength(psi)
3	9.33333	1353.33285
7	14.333333	2078.333285
14	18.433333	2672.833285
28	24.4	3538

The graph between the number of day and the compressive strength in Psi is given below in the Figure 4-6.

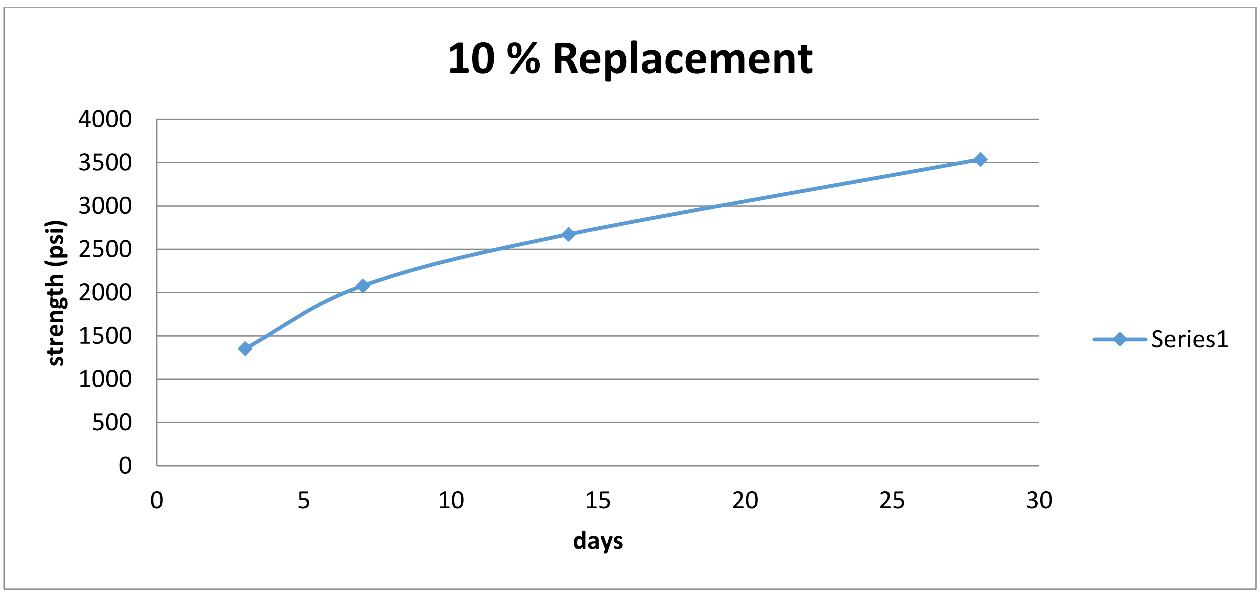

FIGURE 4-6 STRENGTH GRAPH WITH 10% REPLACEMENT

4.6.1.3 Compressive test of concrete with 20% replacement

The compressive strength of concrete made with using natural aggregate at different stages are given in the Table 4-8 below.

TABLE 4-8 COMPRESSIVE STRENGTH OF CONCRETE WITH 20% REPLACEMENT

20% replacement	strength	Column1
3	8.9	1290.5
7	13.666667	1981.666715
14	18.866667	2735.666715
28	22.066667	3199.666715

The graph between the number of day and the compressive strength in Psi is given below in the Figure 4-7.

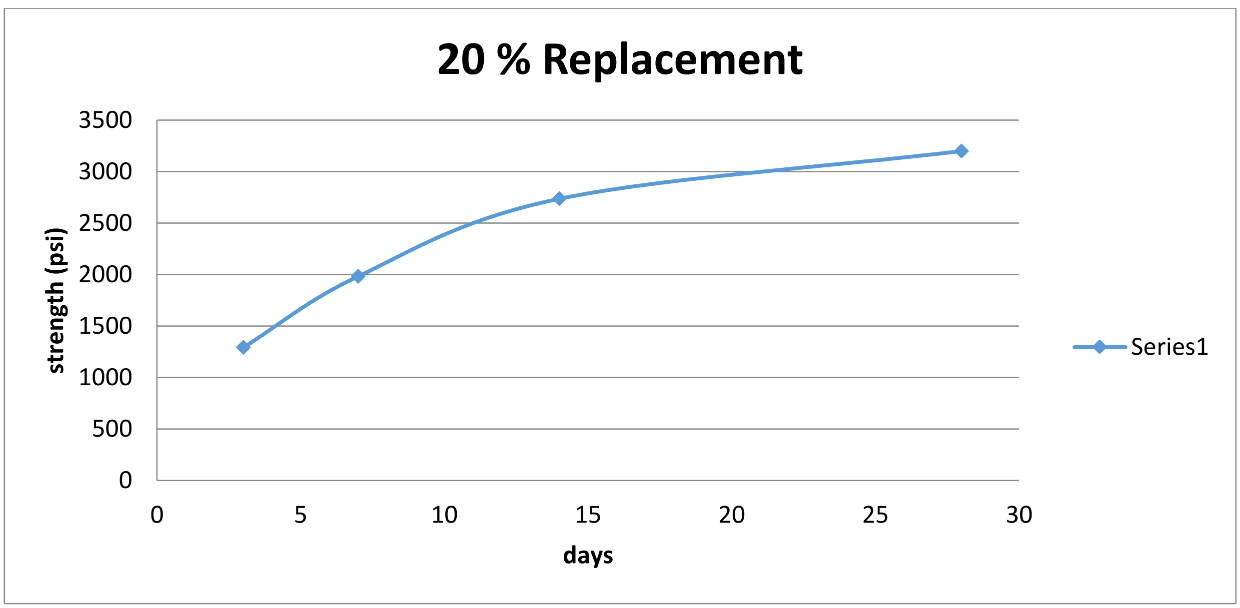

FIGURE 4-7 STRENGTH GRAPH WITH 20% REPLACEMENT

4.6.1.4 Compressive test of concrete with 30% replacement

The compressive strength of concrete made with using natural aggregate at different stages are given in the Table 4-9 below.

TABLE 4-9 COMPRESSIVE STRENGTH OF CONCRETE WITH 30% REPLACEMENT

30% replacement	strength	Column1
3	10.9	1580.5
7	14.833333	2150.833285
14	19.9	2885.5
28	21.0666667	3054.666672

The graph between the number of day and the compressive strength in Psi is given below in the Figure 4-8.

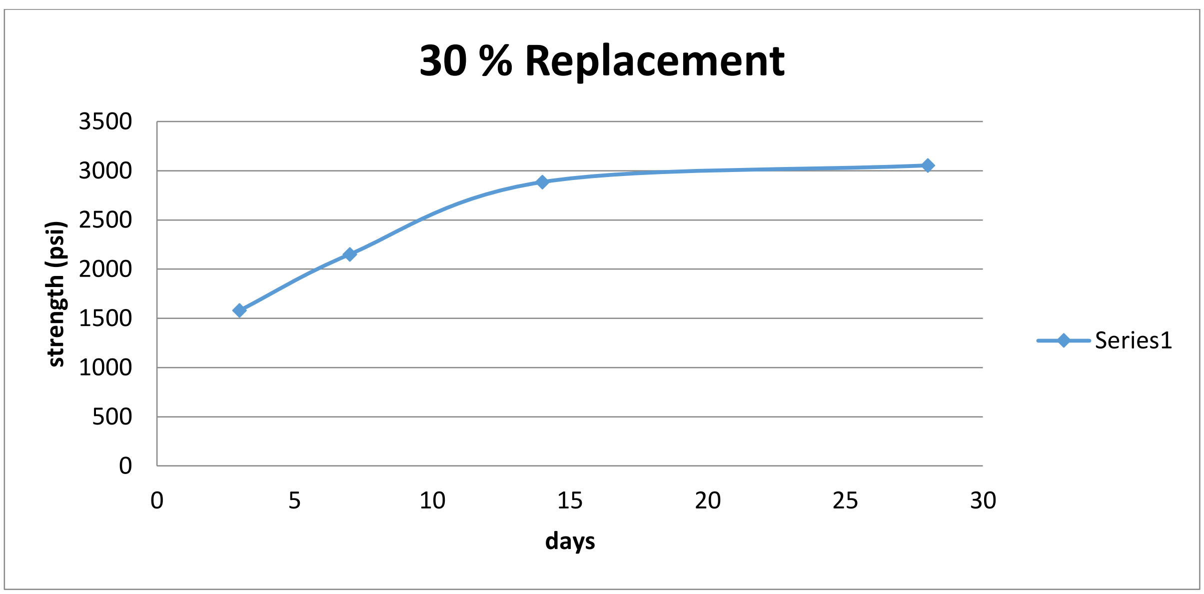

FIGURE 4-8 STRENGTH GRAPH WITH 30% REPLACEMENT

4.6.1.5 Compressive test of concrete with 40% replacement

The compressive strength of concrete made with using natural aggregate at different stages are given in the Table 4-10 below.

TABLE 4-10 COMPRESSIVE STRENGTH OF CONCRETE WITH 40% REPLACEMENT

40%replacement	strength	Column1
3	10.366667	1503.166715
7	12.7	1841.5
14	16.43	2382.35
28	20.066667	2909.666715

The graph between the number of day and the compressive strength in Psi is given below in the Figure 4-9.

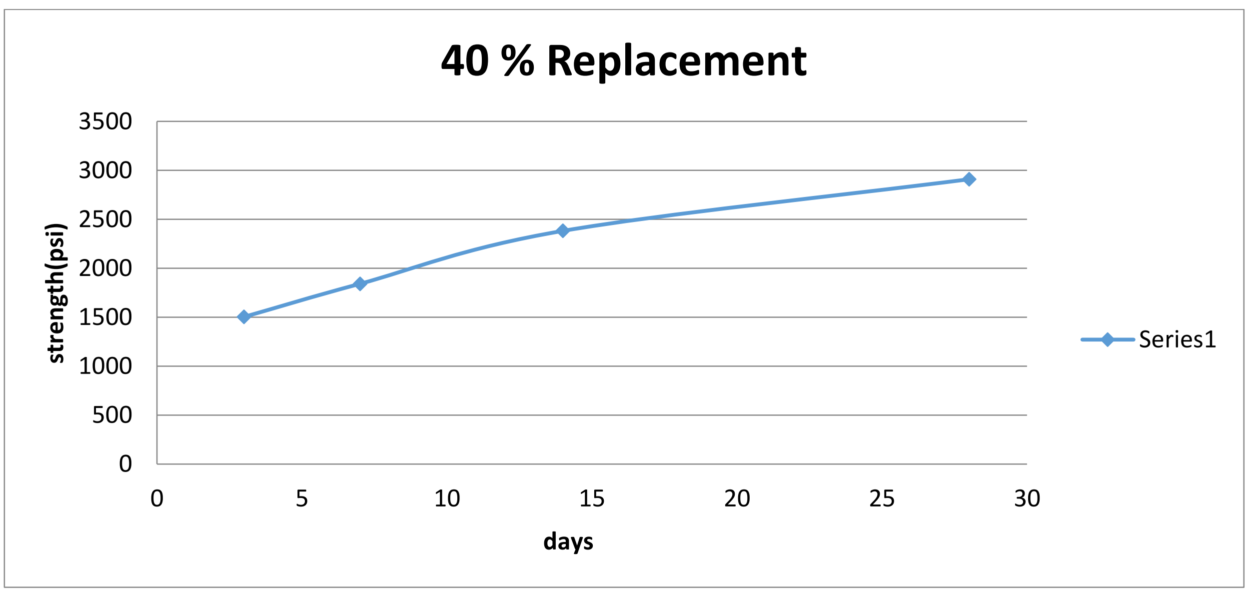

FIGURE 4-9 STRENGTH GRAPH WITH 40% REPLACEMENT

CHAPTER 5

5 Conclusion and recommendations

This chapter will cover the following topics

1. The combined graph of all the batch with different percent of replacement
2. Discussion about the trends at different stages
3. The 28^{th} day strength graph of all the batch
4. Results and Recommendations for future research

The combined graph for all the batches of concrete are given below. The dark blue line in the graph represent the strength of concrete without replacement of recycled aggregate with natural aggregate. The red, green, purple and light blue represent the strength of concrete with replacement of 10, 20, 30 and 40% of natural aggregate with recycled aggregate respectively.

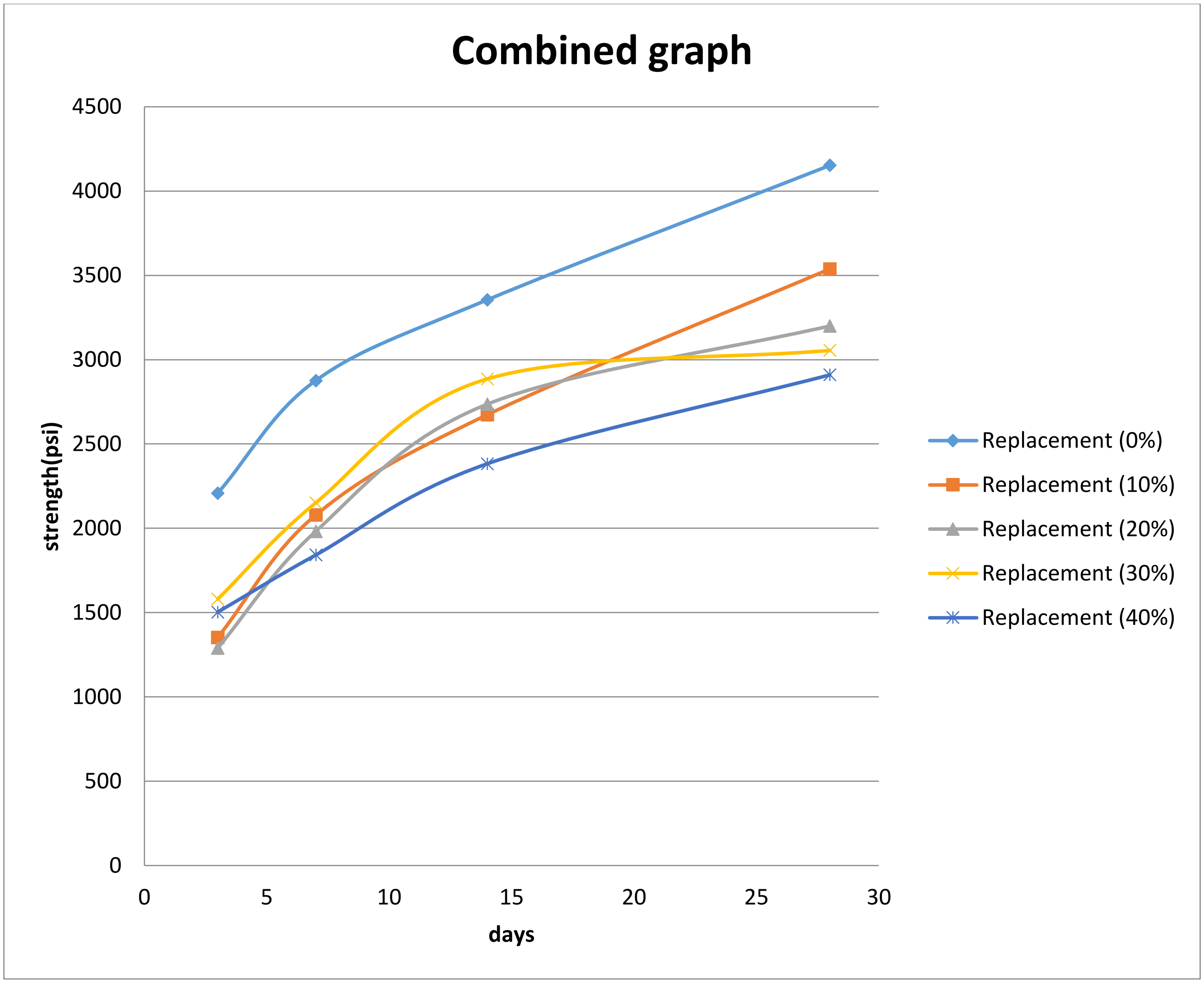

FIGURE 5-1 COMBINED GRAPH OF ALL % OF REPLACEMENT

5.1 Trends

5.1.1 28th days trend

The trend of the graph in the Figure 5-1 shows that at 28th day the strength of concrete decreases as the percentage of replacement of recycled aggregate increases. This trend is due to the fact that the strength of concrete depend on the thickness of interfacial transition zone (ITZ), cracks in the (ITZ) and the strength of the aggregate. As the thickness of (ITZ) is more around recycled aggregate as compared to natural aggregate which make the weak zone in the concrete. Hence by increasing recycled aggregate percentage in the concrete will result in increase in the weak zone of the concrete and thus the strength will be decreased.

The percent reduction in strength of each concrete with recycled aggregate from the concrete with natural aggregate are shown in the Table 5-1 below.

TABLE 5-1 PERCENT REDUCTION IN 28TH DAY STRENGTH

Percent Replacement	Strength Reduction In Percent (%)
40%	29.91
30%	26.42
20%	22.93
10%	14.79

5.1.2 14th day trend

In the above figure the 14th day strength shows that the strength of the concrete without replacement is higher than all of the concrete with different percent of replacement with recycled aggregate.

The strength of the concrete with replacement shows a trend, in which the strength of 30%replacement is highest one, 20 % replacement is second one and 10% replacement is the third one. The strength of the concrete with 40% replacement is lesser then that of all the other concrete which is out of trend.

The trend shows that increasing the % replacement will result in increase in the 14th day strength of concrete. It may be due to the fact that the recycled aggregate contain some particles of unhydrated cement. The extra amount of cement decrease the water to cement ratio and thus increasing the strength.

The concrete with 40% replacement does not match with the trend which may be due to some error in the mixing, casting and curing of concrete. We didn't have much time to repeat the procedure so we put these values in the project. And also we have to check the 28th day strength which was not affected by these error.

The percent reduction in strength of each concrete with recycled aggregate from the concrete with natural aggregate are shown in the Table 5-2below.

TABLE 5-2 PERCENT REDUCTION IN 14TH DAY STRENGTH

Percent Replacement	Strength Reduction In Percent

40%	28.98
30%	13.95
20%	18.43
10%	20.3

5.1.3 7th day trend

In the above figure the 7th day strength shows that the strength of the concrete without replacement is higher than all of the concrete with different percent of replacement with recycled aggregate.

The strength of the concrete with replacement shows that the strength of 30%replacement is highest one, 10 % replacement is second one and 20% replacement is the third one. The strength of the concrete with 40% replacement is lesser then that of all the other concrete.

The strength of concrete with 10%replacement is in-between 20% and 30%replacement concrete. The reason behind such trend is that the contents slurry attached to the surface of recycled aggregate was not constant and it may vary depend on the source of the recycled aggregate. The recycled aggregate in 10% replaced concrete may have greater amount of unhydrated cement contents which result in increased strength of 10% replaced concrete than 20% replaced concrete.

The concrete with 40% replacement does not match with the trend which may be due to some error in the mixing, casting and curing of concrete. We didn't have much time to repeat the procedure so we put these values in the project. And also we have to check the 28th day strength which was not affected by these error.

Apart from the chances of error, it is quite possible that the optimum use of recycled aggregate for a mix design can be in a range of 10-30 % of the total aggregate used in the mix. Above this percentage, if recycled aggregate used will not yield the best results where formwork is to be removed in a short period of time.

The percent reduction in strength of each concrete due to replacement natural aggregate with recycled aggregate are shown in the Table 5-3 below.

TABLE 5-3 PERCENT REDUCTION IN 7TH DAY STRENGTH

Percent Replacement	**Strength Reduction In Percent**
40%	35.95

30%	25.21
20%	31.1
10%	27.75

5.1.4 3rd day trend

In the above figure the 3rd day strength shows that the strength of the concrete without replacement is higher than all of the concrete with various percentages of replacement with recycled aggregate.

The strength of the concrete with replacement shows that the strength of 30%replacement is highest one, 10 % replacement is second one and 20% replacement is the third one. The strength of the concrete with 40% replacement is in between 30% and 10%replaced concrete.

The strength of concrete with 10%replacement is in-between 20% and 30%replacement concrete. The reason behind such trend is that the contents slurry attached to the surface of recycled aggregate was not constant and it may vary depend on the source of the recycled aggregate. The recycled aggregate in 10% replaced concrete may have greater amount of unhydrated cement contents which result in increased strength of 10% replaced concrete than 20% replaced concrete.

The concrete with 40% replacement does not match with the trend which may be due to some error in the mixing, casting and curing of concrete. We didn't have much time to repeat the procedure so we put these values in the project. And also we have to check the 28th day strength which was not affected by these error.

Apart from the chances of error, it is quite possible that the optimum use of recycled aggregate for a mix design can be in a range of 10-30 % of the total aggregate used in the mix. Above this percentage, if recycled aggregate used will not yield the best results where formwork is to be removed in a short period of time.

The percent reduction in strength of each concrete with recycled aggregate from the concrete with natural aggregate are shown in the Table 5-4 below.

TABLE 5-4 PERCENT REDUCTION IN 3RD DAY STRENGTH

Percent Replacement	**Strength Reduction In Percent**
40%	31.96
30%	28.42
20%	41.55

10%	38.75

5.2 28th day strength.

Concrete attains its maximum strength i.e. about 98 % of total strength at 28th day. As for our project only strength at 28th will be considered for the analysis.

The Table 5-5 below shows the 28th day strength of all the batches.

TABLE 5-5 28TH DAY STRENGTH OF CONCRETE

% Replacement	**Strength**
0	4152
10	3538
20	3199
30	3055
40	2954

The above **Error! Reference source not found.** shows the there is decrease in strength as the ercentage of recycled aggregate increases. The percent reduction in strength in 10% replaced concrete is shown in the Table 5-1 which is 14.79%.

The percent reduction in strength in 20% replaced concrete is shown in the Table 5-1 which is 22.93%.

The percent reduction in strength in 30% replaced concrete is shown in the Table 5-1 which is 26.42%.

The percent reduction in strength in 40% replaced concrete is shown in the Table 5-1 which is 29.91%.

The graph for 28th day strength for different replacement percentages is below.

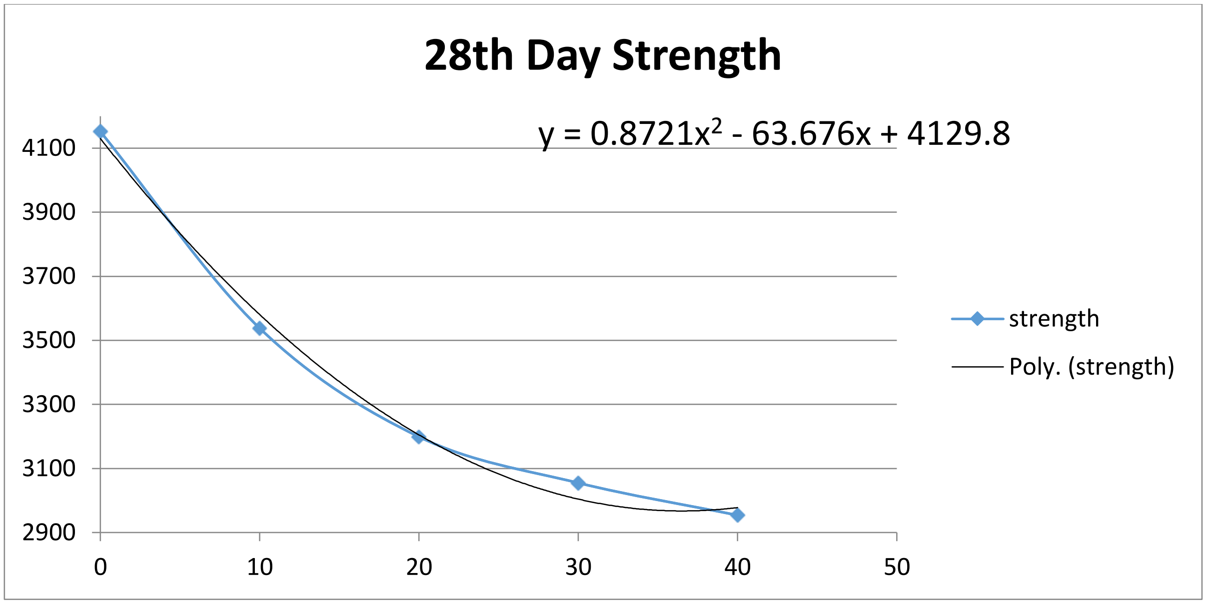

FIGURE 5-2 28TH DAY STRENGTH OF ALL BATCHES

The blue curve line shows the original strength of the replacements while the black line is a second degree trend line which best fit the curve along with the equation written. The graph has a higher slope at the start and gradually decreases as the percentage replacement increases which shows that as the replacement percentage increases the strength reductions decreases gradually i.e. in first case for 10 % replacement the reduction is 14.79 % and in second case for 20 % replacement the strength reduction is 22.93% which is less than the percentage decrease in first case.

In the equation y is the strength and x is the percent replacement. The equation is of second degree polynomial equation and it doesn't fit the original curve completely, and there is some percent of error in the results obtained from this equation. The original values of the curve, the values obtained from the equation and the difference between them are given in the Table 5-6 below.

TABLE 5-6 DIFFERENCE IN ORIGINAL CURVE AND BEST FIT POLYNOMIAL CURVE

Percent Replacement Or Value Of (X) In Equation	Original Curve Value (A) (Psi)	Value From Equation (B) (Psi)	Difference Between A And B C=A-B (Psi)
0	4152	4129.5	22.5
10	3538	3580.25	-42.25
20	3199	3205.12	-6.12

30	3055	3004.41	50.59
40	2954	2978.12	-24.12

5.3 Recommendation

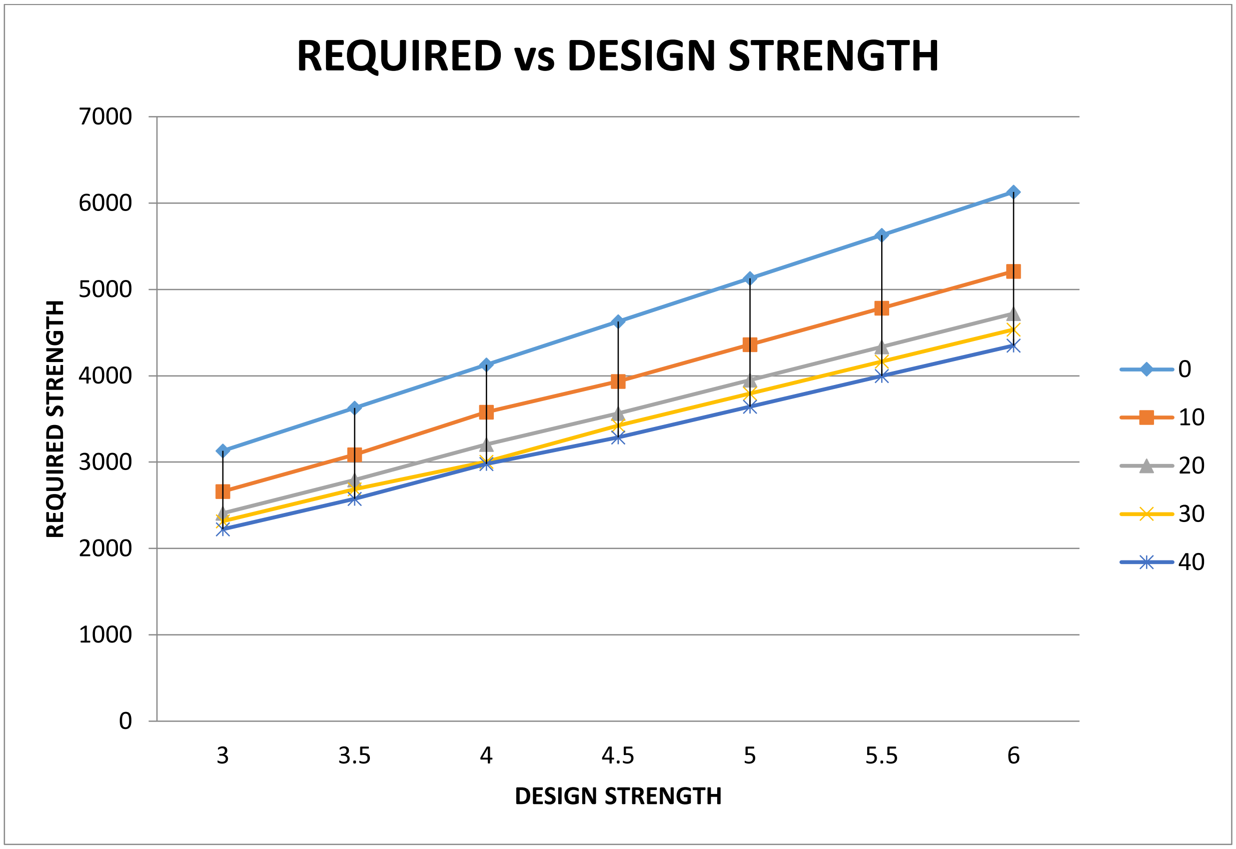

FIGURE 5-3

This graph is made from the previous equation. That equation is extended for 3, 3.5, 4.5, 5, 5.5, 6 Ksi strength of the concrete. For each extention the value is decrease 15% for 10% replacement, 23% for 20% replacement, 26% for 30% replacement and 29% for 40% replacement.

The graph above shows the relationship between required strength and design strength through different percentages as a medium. The horizontal line shows the design strength which we must design according to ACI mix design and the vertical line or y-axis shows the required strength which we need. The sky blue line in the graph shows 0% replacement, orange shows 10% replacement, grey line shows 20% replacement, yellow shows 30% replacement and the blue shows 40% replacement.

For example we want 3000psi strength with 20% replacement so we have to strike a straight horizontal line for the required strength of 3000 and intersect 20 % replacement curve and from that intersection point draw a straight line parallel to y-axis which will intersect the x-axis and the design strength will be find out. Calculate a mix design for that very design strength and you will get the required 3000 psi strength with 20 % replacement.

All these values were calculated for a constant water to cement ratio that is 0.57. This relationship is of much practical use and with the help of this the recycled aggregate can be brought to use.

5.4 Recommendation for Future Research

On the basis of our work and results obtained we recommend that future research can be done using different water to cement ratio to get more graph like above and then combining them. We also recommend the inclusion of some other factors like source of recycled aggregate, the w/c ratio of source of recycled aggregate and the curing condition of source of recycled aggregate which can affect the strength and can be used as variables in studying the behavior of recycled concrete aggregate. This will further help us improving the strength of concrete which is being prepared by the replacement of recycled concrete aggregate.

APPENDIX

LIST OF REFERENCES

- Rasheeduzzafar, khan (1984), “Recycled aggregate – a source of new aggregate, cement concrete and aggregates”.
- M. Kakizaki, M. Harada, T. Soshiroda, S. Kubota.,T. Ikeda, Y. Kasai(1988) “ Strength and Elastic Modulus of Recycled Aggregate Concrete; Demolition and Reuse of Concrete and Masonry.”
- Tabsh (2006) “Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete.”
- M. Etxeberria, E. Vázquez, A.R. Marí (2006) “Microstructure analysis of hardened recycled aggregate concrete”.
- K.K. Sague-Crentsil, T. Brown, A.H. Taylor,(2001) “Performance of concrete made with commercially produced coarse recycled concrete aggregate”
- M. Barra, E. Vázquez,(1998) “Properties of concrete with recycled aggregates: influence of properties of the aggregates and their interpretation, Proceeding of the International Symposium on Sustainable Construction”.
- A. Nealen, S. Schenk,(1998) “The influence of recycled aggregate core moisture on freshly mixed and hardened concrete properties, Darmstadt Concrete— Annual Journal 13 (http://www.b-i-m.de/public/tudmassiv/dacon13nealenschenk.htm).”
- Marta Sánchez de Juan , Pilar Alaejos Gutiérrez (2009) “Study on the influence of attached mortar content on the properties of recycled concrete aggregate”
- Nishbayashi S, Yamura K.(1988) “Mechanical properties and durability of concrete from recycled coarse aggregate prepared by crushing concrete.”
- Nagataki S, Gokce A, Saeki T.(2000) “Effects of recycled aggregate characteristics on the performance parameters of recycled aggregate concrete.”
- Claudio Javier Zega , Angel Antonio Di Maio(2007) “Recycled concrete made with different natural coarse aggregates exposed to high temperature.”
- Zega CJ, Taus VL, Di Maio AA.(2006), “ Effect of entrained air on recycled concrete properties. Cement Concrete Aggregate.”
- Akash Rao a, Kumar N. Jha b, Sudhir Misra(2007),“Use of aggregates from recycled construction and demolition waste in concrete.”
- Khalaf FM, DeVenny AlanS.(2004), “ Recycling of demolished masonry rubble as coarse aggregate in Concrete.”
- N. Fonseca a , J. de Brito a,⇑ , L. Evangelista(2010), “The influence of curing conditions on the mechanical performance of concrete made with recycled concrete waste.”
- Olorunsogo F.(1999), “ Early age properties of recycled aggregate concrete. Exploiting wastes in concrete.”