Use of Cost Effective & Eco Friendly Materials (Green Concrete) in Construction Projects using Demolished Waste

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Abstract— Recycled aggregates are composed of crushed concrete, inert particles processed from the materials that have been already used in the structural constructions and demolition (C & D) debris. The aim of this project is to determine the strength characteristics of recycled aggregates for application in high strength structural concrete, which will give a better understanding on the properties of concrete with recycled aggregates, as an alternative material to coarse aggregate (NA) in structural concrete. The aim of this thesis is to determine and compare the strength of concrete by using different percentage of recycled aggregates. Recycled aggregate is also the type of artificial aggregate which is obtained from Construction and demolition (C&D) wastes. Constructions and demolitions are processes that go one after the other. The demolished building aggregate in India generally goes to waste in landfill operation. Recycling of these waste materials from building demolition can provide a solution to this problem. The investigation was carried out using Specific gravity test, Water absorption test, Aggregate Impact Value test, Crushing value test, Sieve analysis test, Workability test and Compressive strength test. There were total of six batches of concrete mixes, consisting of every 20% increment of recycled aggregate replacement, from 0% to 100%.

Key words: Green Concrete, Demolished Waste

I. INTRODUCTION

Construction and demolitions are processes that go one after the other. The demolished building aggregate in India generally goes to waste in landfills. After few years construction and demolition waste will be more than half of the National total waste in most countries of the world so recycling of these concrete waste materials from building demolition can provide a solution to this problem.

Landfills are becoming increasingly difficult to find, are too remote from the demolition site, or are too costly to maintain. At the same time sources of supply of suitable aggregate for making concrete are continuously being exhausted. The recycling of building demolition waste materials into new buildings can provide a solution to these problems. Grinding reinforced concrete buildings can reduce the volume of land filled debris by roughly 80%. While volume reduction itself is advantageous, recycling of the waste material creates a product that can be sold or used for fill, bank stabilization, pavement for trails and other purposes, thereby reducing further environmental burdens by substituting recycled aggregates for natural virgin aggregates.

Recycling is the act of processing the used material for use in producing new product. The use of naturally available aggregate is getting more and more intense with the advanced development in infrastructure area. In order to reduce the usage of natural aggregate, recycled concrete aggregate can be used as the replacement materials. Recycled concrete aggregate are consists of crushed concrete, inorganic particles processed from the materials that have been already used in the structural constructions and demolition debris.

A. Natural Aggregate (NA)

Naturally occurring aggregates are a mixture of rocks and minerals. A mineral is a naturally occurring solid substance with an orderly internal structure and a chemical composition that ranges within limits. Rocks, which are classified as igneous rocks, sedimentary rocks and metamorphic rocks depending on the origin are normally composed of numerous minerals. For example, granite contains quartz, feldspar, mica and a few other minerals; most lime stones consist of calcite, dolomite and minor amounts of quartz, feldspar and clay. Weathering and erosion of rocks produce particles of stone, silt, gravel, sand and clay some of which can be used as aggregates for concrete.

B. Recycled Concrete Aggregate (RCA)

Recycled concrete aggregate (RCA) is generally produced by two-stage crushing of demolished concrete, and screening and removal of contaminants such as reinforcement, paper, wood, plastics and gypsum. Concrete made with such recycled concrete aggregate is called recycled aggregate concrete (RAC).

C. International Status

It has been estimated that approximately 190 million tons of construction & demolition waste are produced each year in European Union. The Netherland produces about 16 million tons of buildings and demolition wastes per annum in which about 9 million tons are recycled mainly for unbound road base courses. The 285 million tons of per annum construction waste produced in Germany, out of which around 77 million tons are demolition waste. Approximately 70% of it is recycled and reused in new construction work. Approximately 13 million tons of concrete is demolished in France every year whereas in Japan total quantity of concrete debris is in the tune of 10-15 million tons each year. The Hong Kong generates about 20 million tons demolition debris per year and facing serious problem for its disposal. USA is utilizing used in road works and balance in structural concrete work.

D. Indian Status

Central Pollution Control Board has estimated current quantum of solid waste generation in India to the tune of 48 million tons per annum out of which, waste from construction industry only accounts for more than 25%. The total quantum of waste from construction industry is estimated to be 11 to 15 (approximately) million tons per annum out of which 6-10 (approximately) million tons are concrete and brick waste.

E. Applications of Recycled Concrete Aggregate

These are the various applications of RCA in different areas.

1) Concrete Curb and Gutter Mix
2) Granular Base Course Materials
3) Embankment Fill Materials
4) Paving Blocks
5) Backfill Materials
6) Building Blocks

F. Advantages

There are many advantages through using the recycled concrete aggregate. Successful application of recycled concrete aggregate in construction projects has been reported in some European and American countries, as reviewed by Desmyster and Vyncke [19].

1) Durability
2) Environmental Gain
3) Save Energy
4) Job Opportunities
5) Sustainability

G. Disadvantages

Although there are many advantages by using recycled concrete aggregate. But there are still some disadvantages in recycled concrete aggregate. The limited use of recycled concrete aggregate in structural concrete is due to the inherent deficiency of this type of material.

– Hard to have permit
– Lack of Specification and Guidelines
– Water Pollution
– Air Pollution
– Low Quality
– Variations in Quality

II. Literature Review

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

The main aim that testing the recycled aggregate is to find out the result of the strength characteristic on it and analysis whether recycled aggregate is suitable to apply in the construction area. According to Rammamurthy and Gumaster (1998) (25), the compressive strength of recycled aggregate concrete was relatively lower and variation was depended on the strength of parent concrete from the obtained aggregate.

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

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

Nelson and Shing Chai NGO et al., (2004) the investigation was carried out using workability test, compressive test, indirect tensile test and modulus of elasticity test. There were total of eight batches of concrete mixes, consists of every 20% increment of recycled aggregate replacement from 0% to 100%. Moreover, 100% of recycled aggregate mix batches included fly ash, water/cement ratio of 0.36 and 0.43. The workability of concrete considerably reduced as the amount of recycled aggregate increased. This was evaluated through standard slump test and compacting factor test. For strength characteristics, the results showed that a gradually decreasing in compressive strength, tensile strength and modulus of elasticity as the percentage of recycled aggregate used in the specimens increased

M C Limbachiya et al., (2004) showed that plain as well as reinforced concrete can be crushed using primary and secondary crushers to provide crushed aggregate with an acceptable quality to current BS 882 requirements. Because of the attached cement paste in the RCAs, the density of these materials is about 3-10% lower and water absorption is about 3-5 times higher than the corresponding natural aggregates. It is therefore important that density and water absorption of RCA are determined carefully, prior to their use in concrete production. This must be done in order to avoid large variations in properties of hardened concrete as well as in achieving fresh concrete of adequate workability, stability and cohesiveness.

Winston F.K. Fong et al., (2004) discussed the latest application experience of using recycled aggregate in construction projects in Hong Kong and recommends a broader scope of use of recycled aggregates in areas other than ready mixed concrete.

Michał Bołtryk and Dorota Małaszkiewicz et al., (2005) Carried out test to determine compressive strength. Concrete mixtures were produced at recycled aggregate content equal: 0%, 25%, 50% and 75% of coarse aggregate. Compressive strength of recycled aggregate concrete (RAC) showed a decrease of up to 6% compared to natural aggregate concrete (NAC). RAC water absorption was higher compared to NAC because of remains of mortar on its rough surface.

Ismail Abdul Rahman et al., (2009) described the effect of size of recycled aggregate on compressive strength. The 100% of RA used in concrete mix to replace the natural coarse aggregate in concrete with 100 x 100 x 100 cube mm were cast with target compressive strength is 25 MPa. The 28-day compressive strength was crushed at 3, 14, 28 days are reported found that the size of 10mm and 14 mm of RA in RAC is quite similar performance with 10mm and 14mm size of natural aggregate (NA) in natural aggregate concrete (NAC).

Yong, P.C et al., (2009) found that the recycled aggregates that are obtained from site-tested concrete specimen make good quality concrete. The compressive strength of recycled aggregate concrete (RAC) is found to be higher than the compressive strength of normal concrete. Recycled aggregate concrete is in close proximity to normal concrete in terms of split tensile strength, flexural strength and wet density. The slump of recycled aggregate concrete is low and that can be improved by using saturated surface dry (SSD) coarse aggregate.

Tabsh and Abdelfatah (2009) studied the strength of concrete made with recycled concrete coarse aggregate. The toughness and soundness laboratory tests on the recycled coarse aggregate showed higher percentage loss than natural aggregate, but remained within acceptable limits. The compressive and splitting tensile strengths of concrete made with recycled coarse aggregate depend on the mix proportions. In general, the strength of recycled concrete was 10–25% lower than that of conventional concrete made with natural aggregate due to increase in water demand to maintain the specified slump.

R. Kumutha et al., (2010) carried out tests to determine the density, compressive strength, split tensile strength, flexural strength and modulus of elasticity of concrete with and without recycled aggregates. Natural coarse aggregates in concrete was replaced with 0%, 20%, 40%, 60%, 80% and 100% of crushed concrete aggregates. Natural fine aggregate in concrete was replaced with 0%, 20%, 40%, 60%, 80% and 100% of crushed brick aggregates. For strength characteristics, the results showed a gradual decrease in compressive strength, split tensile strength, flexural strength and modulus of elasticity as the percentage of recycled aggregate used in the specimens increased.

Abdelfatah et al. (2010) utilized admixtures in concrete mixes containing demolished concrete as replacement for natural coarse aggregates to compensate for the need of additional water required to increase the workability. The results showed that the use of super plasticizers, instead of additional water, was able to increase the compressive strength of recycled aggregate concrete to a level around the same as that of the control mix containing natural aggregate. This finding is not in agreement with the results obtained by Gull (2011) when testing low strength concrete utilizing recycled concrete aggregate.

Mirza and Saif (2010) studied the effect of silica fume on recycled aggregate concrete characteristics. The percentages of recycled aggregate replacements of natural aggregate used by weight were 0, 50, and 100%, whereas the percentages of silica fume replacements of cement used by weight were 5, 10, and 15%. The results showed that the compressive and tensile strengths values of the recycled concrete aggregate increased as the recycled aggregate and the silica fume contents increased. The study also indicated that in order to accommodate 50% of recycled aggregate in structural concrete, the mix needs to incorporate 5% of silica fume.

Elchalakani (2010) investigated the strength and durability of recycled concrete made from recycled aggregate and wastewater in the UAE. Experimental tests employing standard cubes and cylinders to assess the compressive strength and small beams to evaluate the flexural strength were utilized. The study showed that the effect of recycled aggregate and recycled water on axial and bending strength was found moderate but had a significant effect on durability. To enhance the durability of recycled concrete, the author recommended using ground granulated blast furnace slag and fly ash for any future building construction in the Gulf.

III. EXPERIMENTAL METHODOLOGY

Regarding the objectives, laboratory works need to be done to obtain the data and information related to the project. The data is the reference of study experiment that has to be done. Experiments needed to be done to achieve the objectives given are sieve analysis, specific gravity, water absorption, impact, & crushing strength of aggregates. Compressive strength and workability of hardened concrete.

A. *Materials & Testing Methods*

1) *Materials Used:*

1) Conventional materials- Portland cement, fine aggregates and coarse aggregates were purchased from the local vendors.
2) RCA- The main source of recycled concrete aggregate was demolished structure mainly the columns and beams which were free from any reinforcement or other contaminants, cubes from this material were casted and tested in the laboratory. The local crushing plants were not able to crush the concrete waste and thus the crushing and sieving had to be done manually. The concrete rubble remains were broken initially manually and then sieving was done using IS sieves. The process generated, recycled concrete aggregate-10mm and recycled concrete aggregate 20 mm size.

2) *Testing Methods:*

a) Sieve Analysis Test:

Fineness modulus (F.M.) of aggregate is an index number which gives an idea about the coarseness or fineness of an aggregate.

Fineness modulus of an aggregate is approximate proportion of the average size of particles in the aggregate. Fineness modulus is determined by adding the cumulative percentage of material retained on each sieve and dividing the sum of cumulative percentage of material retained on each sieve by 100. In this method, the fineness modulus of coarse and fine aggregate are determined separately. Prescribed values of F.M. is higher for coarse aggregate (i.e stone metals etc.) and is as follows

For 20 mm size = 6 to 6.9
40 mm size = 6.9 to7.5
For all in aggregate
20mm size = 4.8 to 5.1
25mm size = 5.1 to 5.5

b) Specific Gravity Test:

Specific gravity is the ratio of the weight of given volume of dry aggregate to the weight of equal volume of distilled water.

c) Water Absorption Test:

Specific gravity is the ratio of the weight of given volume of dry aggregate to the weight of equal volume of distilled water.

Stones having higher water absorption values are porous and hence weak. They are generally unsuitable unless found acceptable based on crushing and grinding. The sample is weighted on water and the buoyant weight is found. The aggregate is taken out and weighted after the surface is dried. The specific gravity can be calculated by dividing dry weight of aggregate by weight of equal volume of water.

The water absorption is expressed as percentage water absorption in terms of oven dried weight of aggregate. The specific gravity of rock varies from 2.6 to 2.9. Rock specimen having more than 0.6 percent of water absorption is considered unsatisfactory.

d) Impact Test:

The property of a material to resist impact is known as toughness. Due to movement of vehicles on the road the aggregates are subjected to impact resulting in their breaking down into smaller pieces. The aggregates should therefore have sufficient toughness to resist their disintegration due to impact. This characteristic is measured by impact value test. The aggregate impact value is a measure of resistance to sudden impact or shock, which differs from its resistance to gradually applied compressive load.

e) Crushing Value Test:

The strength of coarse aggregate may be determined by aggregate crushing strength test. The aggregate crushing value gives a relative measure of the resistance of an aggregate sample to crushing under gradually applied compressive load.

Fig. 1: Crushing Value Test using Compression Testing Machine

f) Workability Test of Fresh Concrete:

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

– Consistency: The degree of consistency is dependent on the nature of works and type of compaction.
– Water/Cement Ratio or Water Control of a Concrete: Water/cement ratio is the ratio of water in a mix to the weight of cement. The quantity of water required for a mix depend on the mix proportions, types and grading of aggregate.
– Grading of Aggregate: The smooth and rounded aggregate will produce a more workable concrete than the sharp angular aggregate.
– Cement Content: The greater workability can be obtained with the higher cement content.

Fig. 2: The Apparatus for Slump Test

g) Compression Test

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

The specimens used in the compression test were cubes of 150 mm X150 mm X 150 mm size. Six specimens were used in the compression testing for every batch of mix. Differences of the strength among the different percentage of recycled aggregate used at the age of 7 and 28 days was also indicated through the compression test. The compression testing procedures was according to the Indian Standard Code.

Fig. 3: Setup of Compression Testing machine

IV. Experimental Investigation

A. Mix Design and Casting of Concrete

1) Proportioning of Concrete:

Before having any process of concrete mixing, the selection of the mix materials and their proportion must be done through a process called mix design. There are various methods to determine the concrete mix design. Six different batches of mixtures were determined in this thesis.

The initial mix batch is using 100% natural aggregate (NA) was used. In second mix batch 80% natural aggregate (NA) and 20% recycled aggregate (RA). Successive batches were made by successively adding 20% extra recycled aggregates and corresponding decrease in the NA as shown in Table-1

First batch of mixture called a control mixture used only natural aggregates (NA), and five successive mixtures with increasing percentage of recycled aggregate and corresponding decrease of natural aggregate from 20% to 100% by weight. All these mixtures were prepared with cement, and aggregate in the proportion by weight, and were expected to achieve a target compressive strength of not less than 39.9 MPa at the age of 28 days.

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

Table-1 Percentage of Aggregate used in all 6 Batches of Mixes

B. Mix Design D.O.E. (Department of Environment Method)

1) For 100% Natural Aggregate:

Step-I is to find out the target mean strength.

Target mean strength = Specified characteristic strength + Std. deviation × risk factor

= 30+ 6 x 1.65

= 39.9 Mpa

Step-II is to find out the water cement ratio for 39.9Mpa concrete

For this for OPC uncrushed aggregate for W/C ratio of 0.55, 28 days compressive strength is 49 Mpa. Find an intersection point for 49 Mpa and 0.5 W/C ratio. Draw a dotted line curve parallel to the neighboring curve. From this curve read off the W/C ratio for a target mean strength of 30 Mpa.

The water cement ratio is = 0.7

Check this W/C ratio from durability consideration from Table-9.20 the maximum W/C ratio permitted is 0.55 adopt lower of the two

Therefore adopt W/C ratio of 0.55

Next decide the water content for slump of 60mm (highest slump is taken), 20mm crushed aggregate

The water content is 210kg/m^3

With W/C of 0.5 and water content of 210kg/m^3, the cement content works out to be 210/0.55=381.82kg/m^3

Check this cement content with that of durability requirement minimum cement content from durability point of view is 325kg/m^3.Adopt greater of the two.

Therefore adopt cement content =381.82kg/m3

Next, find out the density of fresh concrete for water content of 210kg/m^3

20mm uncrushed aggregate of specific gravity 2.75

The wet density = 2475kg/m^3

Next, find the weight of total aggregate

2475-(210+381.82) =1883.18kg/m^3

Next, find the percentage of fine aggregates

For 20mm aggregate size, water cement ratio of 0.55

Slump of 60mm, for 50% fine passing through 425µ sieve, the percentage of

F.A. =35 percent

Weight of F.A. =1883.18X (35/100) =659.11kg/m^3

Weight of C.A. = 1883.18-659.11=1224.07kg/m^3

Estimated quantities in kg/m^3

Cement=381.82kg/m^3

F.A.=659.11kg/m^3

C.A. =1224.07 kg/m^3

Water =210 kg/m^3

Wet density =2475 kg/m^3

2) For 100% Recycled Aggregate

Step-I is to find out the target mean strength.

Target mean strength=Specified characteristic strength + Std. deviation × risk factor

= 30 + 6x 1.65

= 39.9 Mpa

Step-II is to find out the water cement ratio for 39.9 Mpa concrete

For this for OPC uncrushed aggregate for W/C ratio of 0.55, 28 days compressive strength is 49Mpa. Find an intersection point for 49Mpa and 0.5W/C ratio .Draw a dotted line curve parallel to the neighbouring curve. From this curve read off the W/C ratio for a target mean strength of 30 Mpa.

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Check this cement content with that of durability requirement given. .minimum cement content from durability point of view is 325kg/m^3.Adopt greater of the two.

Therefore adopt cement content =381.82kg/m3

Next, find out the density of fresh concrete for water content of 210kg/m^3

20mm uncrushed aggregate of specific gravity 2.85

The wet density = 2550kg/m^3

Next, find the weight of total aggregate

2550-(210+381.82) =1958.18kg/m^3

Next, find the percentage of fine aggregates from fig 11.5(b)

For 20mm aggregate size, W/C ratio of 0.55

Slump of 60mm, for 50% fine passing through 425µ sieve, the percentage of

F.A. =35 percent

Weight of F.A. =1958.18X (35/100) =685.36kg/m^3

Weight of C.A. = 1958.18-685.36=1272.82kg/m^3

Estimated quantities in kg/m^3

Cement=381.82kg/m^3

F.A.=685.36kg/m^3

C.A. =1272.82 kg/m^3

Water=210 kg/m^3

Wet density=2550kg/m^3

	Cement	Sand	N.A.	R.A.	Water
100%	9.9kg	21.72kg	-	23.49kg	5.5lit
80%	9.9kg	21.72kg	4.7kg	18.79kg	5.5lit
60%	9.9kg	21.72kg	9.40kg	14.09kg	5.5lit
40%	9.9kg	21.72kg	14.09kg	9.40kg	5.5lit
20%	9.9kg	21.72kg	18.79kg	4.7kg	5.5lit
0%	9.9kg	21.72kg	23.49kg	-	5.5lit

Table 2: Proportion of each Mix Materials for Six Cubes

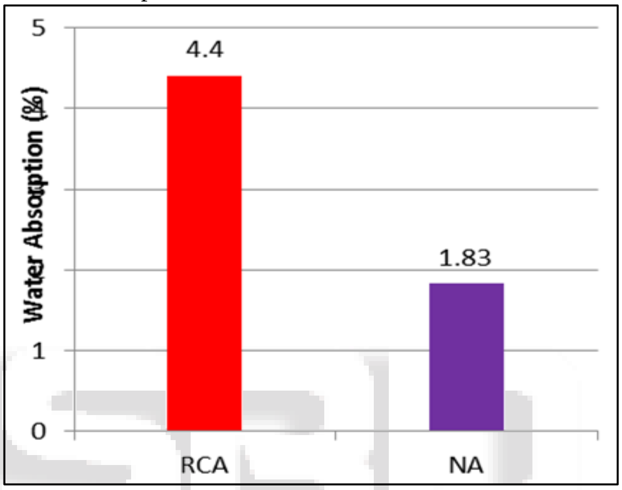
C. Water Absorption

Water absorption is the total amount of moisture absorbed by the aggregate when immersed in water for 24 hrs. The water absorption capacity is based on the saturated surface dry (SSD) condition and oven dried condition. The amount of water in a concrete mixture has direct effect on the setting time and compressive strength of the concrete specimen. Moisture content of the aggregate has to determine first before preparing a mixture for a particular size aggregate. Before making mixture either the aggregates has to be moistened to surface dry condition or surplus water as per the percentage, has to be added to the mixture.

The water absorption capacity of recycled aggregate (RA) is higher than natural aggregate (NA). The average water absorption of recycled aggregate (RA) is around 4.4%, but water absorption of natural aggregate is only 1.83% .This shows that water absorption of recycled aggregate is around 2.5 times of natural aggregate. This result shows that more water needed to be added when using recycled aggregate in the concrete mixing to get an acceptable workability.

S. No.	Details	RCA (gms)	NA (gms)
1	Wt. of empty Container = W1	2.000	2.000
2	Wt. of soaked aggregates + Container = W2	3.500	4.300
3	Wt. of oven dried aggregates + Wt. of container = W3	1.934	1.958
4	% Water absorption = (W1-W3/W2-W1)*100	4.4%	1.83%

Table 3: Proportion of each Mix Materials for Six Cubes



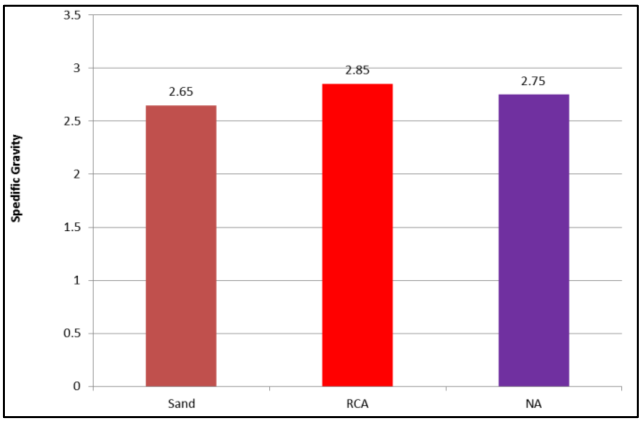
Graph 1: Water Absorption of Aggregates

D. Specific Gravity

The specific gravity of natural aggregate (NA) is around 2.75 and recycled aggregate (RA) is having 2.85 this means that the recycled aggregate is stronger than the natural aggregate in this case. Fine aggregate is having the specific gravity value of 2.65.

S. No	Details	RCA	NA	Sand
1)	Wt. of empty Pycnometer =W1	0.644 kg	0.644 kg	0.644kg
2)	Wt. of Pycnometer + Aggregates/Sand =W2	0.844 kg	0.848 kg	0.848kg
3)	Wt. of Pycnometer + Aggregates + Water =W3	1.632 kg	1.632 kg	1.629kg
4)	Wt. of Pycnometer + Water = W4	1.502 kg	1.502 kg	1.502kg
5)	Specific Gravity=(W2-W1)/(W2-W1)-(W3-W4)	2.85	2.75	2.65

Table 4: Specific Gravity test



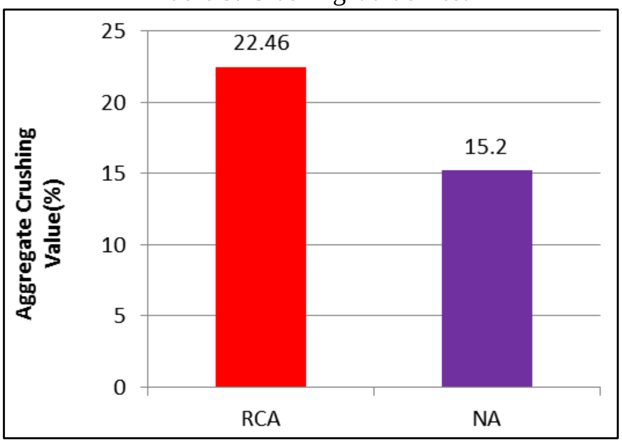
Graph 2: Specific Gravity of Aggregate

E. Aggregate Crushing Value and Impact Value

From the result of crushing value test we come to know that the RA is having more resistance to the wear and tear than the NA. Aggregate Impact Value test is the good indicator of strength and durability from the test results we can say that natural aggregate and recycled aggregate are having wide difference of impact value and crushing value, which again shows that rock of recycled aggregate (RA) is stronger than that of natural aggregate.

Sample	Total Wt. of dry sample (W1)	Weight of fine passing 2.36mm IS sieve (W2)	Aggregate crushing Value = (W2/W1)*100
Recycled Concrete Aggregate (RCA)	3.25kg	0.730kg	22.46%
Natural Aggregate (NA)	3.25kg	0.494kg	15.20%

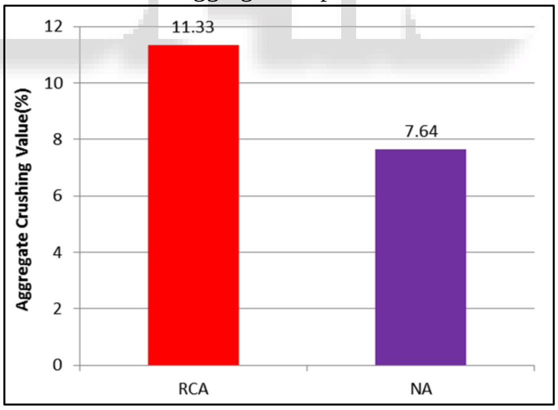
Table 5: Crushing Value Test



Graph 3: Crushing Value of Recycled Aggregate and Natural Aggregate

S. No	Details	RA			NA		
		Trial 1 (kg)	Trail 2 (kg)	Avg. (kg)	Trial1 (kg)	Trail2 (kg)	Avg. (kg)
1)	Total wt. of aggregates sample filling the cylindrical measure= W1	0.546	0.586	11.33%	0.614	0.616	7.64%
2)	Wt. of aggregates passing 2.36mm sieve after the test= W2	0.066	0.062		0.054	0.040	
3)	Wt. of aggregates retained on 2.36mm sieve after the test = W3	0.898	0.524		0.558	0.570	
4)	Difference in Wt.=W1-(W2+W3)						
5)	Aggregate impact value= (W2/W1)*100	12.08%	10.58%		8.79%	6.49%	

Table 6: Aggregate Impact Value test



Graph 4: Impact Value of Recycled Aggregate and Natural Aggregate

F. Compression Strength Test Result and Analysis

The compression strength test by using Compression Testing Machine (CTM) indicates an decreasing trend of compressive strength on the other hand it was more than the target strength (i.e. 39.9 MP) a in the early age of the concrete specimens up to 60% of recycled aggregate. Above 60% addition of recycled aggregate in the concrete mixture the compressive strength decreases up to 34.0 MPa which was less than the target mean strength. It shows that the strength of recycled aggregate (RA) specimens is lower than natural aggregate (NA) specimens.

V. TEST RESULTS AND ANALYSIS

Series of tests were carried out on the materials, fresh and hardened concrete to obtain the workability, strength characteristics of recycled aggregate (RA) for the potential application as a structural concrete. The results for material tests like water absorption test, specific gravity test, Aggregate crushing value test, Aggregate Impact Value (AIV) test are given in the Table-7 below. The test results on fresh concrete are arranged in Table-8 below. Compressive strength of hardened concrete is reported in Table-9.

S. No.	Particulars	Natural Aggregate	Recycled Aggregate	Sand
1	Water Absorption	1.83%	4.4%	-
2	Specific gravity	2.75	2.85	2.65
3	Agg. Crushing Value	15.20 %	22.46 %	-
4	Agg. Impact Value	7.64%	11.33%	-

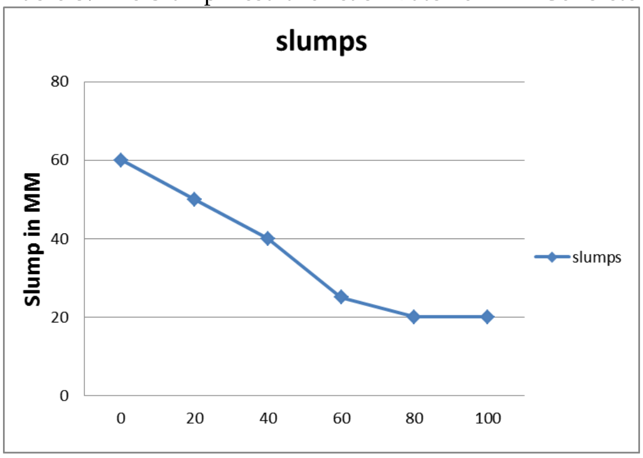
Table 7: Final Result of all tests on Materials

A. *Slump Test Result and Analysis*

The slump test indicates a decreasing trend of workability when the percentage of recycled aggregate increased. Table-8 below shows the average slump recorded during the test. Graph-5 below shows a graphical representation of slump height.

Percentage of Recycled Aggregate in the mix	Percentage of Recycled Aggregate in the mix	Slump (mm)
0%	100%	60
20%	80%	50
40%	60%	40
60%	40%	25
80%	20%	20
100%	0%	20

Table 8: The Slump Result for each Batch of Mix Concrete



Graph 5: Variation in Slump Value

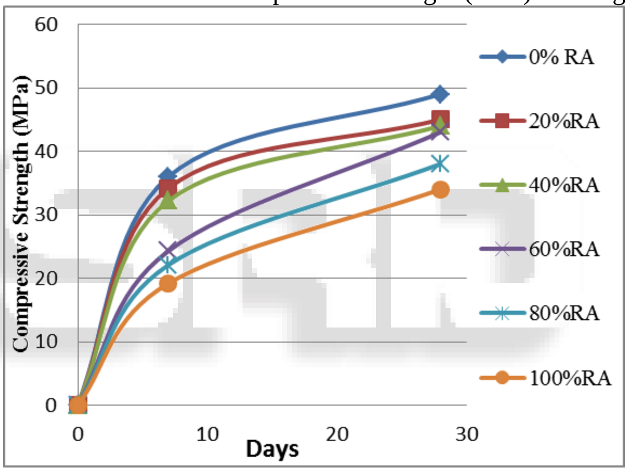
According to these test results, we found that the highest slump obtained was 60 mm and the lowest slump was 20 mm. From these tests results we can say that the workability of the concrete mix was tending to harshness with the increase in the replacement level of natural aggregate with recycled aggregate.

B. *Compressive Strength Test Result*

The compressive strength test by CTM (Compression Testing machine) shows an increasing trend of the compressive strength with age of the concrete specimens. However, it shows that the compressive strength of the recycled aggregate (RA) specimens is lower than the natural aggregate (NA) specimens. Table-9 below shows the increase of the compressive strength with age recorded during the test. Graphs-6 below shows the variation in the compressive strength which exhibiting decreasing trend in successive batches, which containing higher replacement levels.

% of RA	0%	20%	40%	60%	80%	100%
7 Days	36.0 MPa	34.2 MPa	32.2 MPa	24.3 MPa	22.1 MPa	19.2 MPa
28 Days	49.0 MPa	45.0 MPa	44.0 MPa	43.0 MPa	38.0 MPa	34.0 MPa

Table 9: Variation of Compressive Strength (MPa) with Age



Graph 6: Variation in Compressive Strength with Age and increasing % of RA

The target strength for this thesis was 39.9 MPa. Obtained results, shows that the batches that met the target mean strength were having 0%, 20%, 40% and 60% recycled aggregate (RA). The compressive strength for other batches is around 38 MPa. At the same time as using the recycled aggregate the compressive strength of the concrete a specimen for 100% recycled aggregate with 0.55 W/C ratio is 34.00 MPa, which almost met the target mean strength.

The test results also show that the concrete specimens with higher percentage of replacement of recycled aggregate (RA) gave the lowest strength, as compared to the concrete specimens with lesser recycled aggregate (RA).

VI. CONCLUSION AND RECOMMENDATIONS

A. *Conclusion*

The laboratory test results indicates that as the percentage of Natural Aggregate in the mixture decreases by replacing the Recycled Aggregate, the corresponding strength of these mixtures goes on decreasing, however up to the 60% replacement level, it achieves target mean strength. Hence, for the structural concrete Natural Aggregate can be replaced by the Recycled Aggregate up to 60% range.

The workability of the concrete considerably reduces as the amount of recycled aggregate increases in the concrete mixture.

This research project was targeted to determine the strength characteristics of Recycled Aggregate Concrete (RAC) for potential application in the structural concrete.

Whenever recycled aggregate is used, water content in the concrete mixture has to be monitored carefully, due to increased water absorption capacity of recycled aggregate.

B. Recommendations for Future Work

Further testing and studies on the recycled aggregate concrete are greatly recommended to indicate the strength characteristics for application in the structural concrete. Following are some of the recommendations for future studies:

1) Although by decreasing the W/C ratio, recycled aggregate can achieve high strength concrete which leads to the low workability. Therefore, it is suggested that studies be made to improve the workability without hampering the strength by use of admixtures such as super plasticizer and silica fume.
2) Additional investigations and laboratory tests are suggested on the strength characteristics and size, shape, texture of recycled aggregate.
3) It is also recommended that testing can be done on finished components like concrete beams, slabs and walls made from recycled aggregate concrete, to access their collapse loads.
4) Some mechanical properties such as creep, abrasion and shrinkage can also be studied by further research work.
5) More trials with different particle sizes of recycled aggregate and finer range of percentage of replacement (e.g. 5%, 10%, 15%, 20% etc) of recycled aggregate are recommended to get the finer outcomes and higher strength characteristics in the recycled aggregate concrete (RAC).

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