EVALUATION OF FRESH-STATE BEHAVIOR OF RECYCLED AGGREGATE CONCRETE (RAC)

Thesis Submitted
In Partial Fulfillment of the Requirements for the Degree of

Masters of Technology

in

STRUCTURAL ENGINEERING

by

NISHANT RANA
2K22/STE/09

Under the Supervision of

ALOK VERMA
Professor, Department of Civil Engineering
Delhi Technological University

Department Of Civil Engineering
DELHI TECHNOLOGICAL UNIVERSITY, DELHI
(Formerly Delhi College of Engineering)
Shahbad Daulatpur, Main Bawana Road, Delhi-110042, India

May, 2024

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Shahbad Daulatpur, Main Bawana Road,Delhi-42

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I, **Nishant Rana** hereby certify that the work which is being presented in the thesis entitled **Evaluation of Fresh-State Behavior of Recycled Aggregate Concrete (RAC)** in partial fulfilment of the requirements for the award of the Degree of Master in Technology, submitted in the Department of **Civil Engineering**, Delhi Technological University is an authentic record of my own work carried out during the period from **August, 2023** to **May, 2024** under the supervision of **Prof. Alok Verma**

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Shahbad Daulatpur, Main Bawana Road,Delhi-42

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Alok Verma
Professor, Civil Engineering Department
Delhi Techological University

Date: 31/5/24

EVALUATION OF FRESH-STATE BEHAVIOR OF RECYCLED AGGREGATE CONCRETE (RAC)

NISHANT RANA

ABSTRACT

As we all know that worldwide demand for virgin or natural aggregates has put strain on existing natural resources and led to several environmental problems. On the other hand Construction & Demolition waste has turned out to be a major issue in the recent years. In such an alarming situation tons of research work is being done to find a solution to this dilemma. Recycled Aggregates have turned out to be the most viable and feasible alternative to natural aggregates which would not only help in promoting sustainable development but environmental preservation as well. Recycled aggregates (RCA) are obtained by crushing of construction demolition debris and are surely the materials for the future. Many countries have now made guidelines to incorporate the use of recycled aggregate and have started wide-scale use of recycled aggregates in construction projects. Based on the extensive research in recent years it has been shown that recycled aggregates can be well used to manufacture concrete with characteristics similar to that of concrete produced using natural aggregate.

Nevertheless, it is still unclear to what extent recycled aggregates can replace natural aggregates in concrete without materially altering the concrete's short-

term or fresh-state qualities. This research aims to investigate the Fresh-State properties of RAC and determine the percentage of recycled aggregate that can be substituted for natural aggregate in M30 grade concrete to achieve the required workability and strength while utilizing Portland Pozzolana Cement based on Fly Ash.

In this experimental investigation trial mixes were prepared with varying proportions of recycled aggregate and after concrete was produced it was tested for its fresh-state behavior.

The research methodology involves preparing concrete mixtures or trial mixes with varying proportions of recycled aggregates and conducting comprehensive testing to assess their mechanical performance. Laboratory tests, including compressive strength and durability assessments are carried out to evaluate the behaviour of fresh-state behaviour of RAC

Generally, workability and strength are the two main properties that consumers demand for construction activities. This investigation clearly demonstrates that RA can be fully used to replace NA in concrete in terms of workability and strength for small scale constructions.

ACKNOWLEDGEMENT

I would like to thank Professor **Alok Verma,** Department of Civil Engineering, Delhi Technological University for his invaluable guidance throughout the course of this research work. He gave me the motivation and strong guidance that I certainly needed during my research and was an exemplary model of a person and professor that I would always cherish.

Prof Alok Verma generously offered me his time and the strong guidance which was necessary for the completion of this project. I'm highly grateful for his unconditional help and insight, which were of great help for the completion of this project and interpretation of its results.

I am also grateful for laboratory assistance by the lab attendant of our department and Assistant Prof. B.R.G Robert sir's lab for providing and maintaining such a well-equipped laboratory.

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Abbreviations/Symbols	**Descriptions**
RAC	Recycled Aggregate Concrete
NA	Natural Aggregate
RA	Recycled Aggregate
w/c	Water Cement Ratio
fRCA	fine Recycled Concrete Aggregates

LIST OF ABBREVIATIONS AND SYMBOLS

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Concrete is a ubiquitous construction material renowned for its versatility, durability, and widespread usage across the globe. Composed primarily of cement, water, and aggregates such as sand, gravel, or crushed stone, concrete has been integral to construction practices for millennia. Its enduring popularity can be attributed to its remarkable strength and resilience, making it indispensable for a myriad of construction projects ranging from towering skyscrapers to intricate infrastructure systems.

The longevity of concrete can be attributed to its simple yet robust composition, which allows for easy fabrication and adaptation to diverse applications. Its ability to withstand heavy loads, harsh environmental conditions, and the test of time has solidified its status as a cornerstone material in the construction industry. Additionally, advancements in concrete technology, including the introduction of supplementary cementitious materials and chemical admixtures, have further enhanced its performance and versatility.

Concrete offers a multitude of advantages, including exceptional structural strength, durability, and fire resistance. Its ability to resist compression and provide long-term stability makes it ideal for supporting large-scale structures. Furthermore, concrete structures typically require minimal maintenance, resulting in cost savings over their lifespan. Additionally, concrete's thermal mass properties provide energy-efficient solutions for maintaining comfortable indoor environments.

Despite its numerous benefits, concrete does have some disadvantages. One significant drawback is its susceptibility to cracking, particularly due to shrinkage during curing or exposure to temperature variations. Cracks can compromise the integrity of concrete structures and lead to issues such as water infiltration and corrosion of reinforcement. Additionally, the production of cement, a key component of concrete, is energy-intensive and contributes to carbon dioxide emissions, raising environmental concerns.

In conclusion, concrete's enduring popularity is rooted in its strength, durability, and adaptability, which have made it indispensable in the construction industry for centuries. While it offers numerous advantages, such as structural stability and energy efficiency, it also presents challenges such as cracking and environmental impact. Nonetheless, ongoing research and innovation aim to address these challenges and further improve the sustainability and performance of concrete for future generations.

Utilizing Construction and Demolition (C&D) Waste is unquestionably an important step towards sustainable development in the construction industry and handling of construction waste. The current demand for natural aggregates has put strain on natural resources and depleting them. Thus environmental protection by waste management and recycling is the need of the hour. Current statistics forecast the demand of construction aggregate to rise by 2.6% every year to reach 49.5 billion metric tons till 2025 with Asia and Pacific being the largest consumers. This project is based on improving strength and fresh state properties of Recycled Aggregate Concrete. The Construction and Demolition waste might be utilized as aggregates for the fresh concrete by crushing it into the small pieces like the size of aggregates. The construction will become more economical by using Recycled Aggregates due to substantial reduction in cost. Over the years many researches have been undertaken that have proved that recycled aggregates have different properties in comparison to natural ones. Hence a need arises to study the fresh state behavior of RAC and find out that up to what percentage recycled aggregate can be used to replace natural ones in concrete giving the desired strength and other properties.

1.2 WHY RECYCLED AGGREGATES?

At present India produces about 25.75 MT of construction and demolition waste annually. As per data from reports provided by Central Pollution Control Board in India, of the 50 million tons of solid waste produced 15.5-million-ton waste is generated by the construction industry alone and of this about 3% is being utilized.

In India the total demand for aggregates in the year 2019 was 5075 million metric tons and of this demand only 3-4% was satisfied with recycled aggregate. This proves that there is a tremendous scope to reduce construction costs and utilize and manage construction waste effectively.

Utilizing recycled aggregates results in a significant cost reduction by about 35-41% and CO^2 emission by about 25-28% due to discarding at public/private disposal facilities.

1.2 ADVANTAGES AND DISADVANTAGES

1.2.1 Advantages

1. Using recycled aggregates makes your concrete economical and significantly reduces construction cost.
2. It upholds the principle of sustainable development by efficient management of waste and reducing the strain on natural resources.
3. Recycled aggregate can be used in place of natural ones to generate structural concrete that can be satisfactory and possibly even of high quality, according to significant research and analysis.
4. Using recycled aggregates in your structure can provide you incentives from the Government or the concerned authorities in the form of tax rebates.

1.2.2 Disadvantages

1. Recycled aggregates are more angular and flaky as compared to natural aggregates.

2. They have high water absorption and porosity due to adhered cement paste and mortar.
3. They also have low crushing and abrasion resistance.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

In order to comprehend the phenomena and the state of the utilization of steel fiber in concrete today, a thorough literature review was conducted for this chapter. A literature assessment was necessary to determine the research gaps in the suggested topic ofstudy and to comprehend the technique for carrying out future experimental studies to investigate the impact of steel fiber aspect ratio at various temperatures.

2.2 REVIEW OF STUDIES ON EFFECT OF RECYCLED AGGREGATES ON PROPERTIES OF CONCRETE

Nedeljkovic (2021): A thorough and current assessment of the literature on the key developments, advancements, and constraints in the structural uses and characterization of fine recycled concrete aggregates (fRCA) depicted there are no set guidelines for the amount of (fRCA) that can be added to concrete. The ideal percentage of fRCA is discovered to be 25%, and this percentage has no influence on the strength of the concrete. As the amount of fRCA is increased, the specific surface area increases, which raises the cement content and water demand.

Aliakbar et al. (2020): Results of studies on time-dependent, durable, and mechanical properties depicted that concrete's long-term cracking tensile, flexural and compressive strength as well as its elastic modulus diminish with an increase in RCA%.

Minkwan Ju et al. (2019): Examining the mechanical properties of concrete with recycled fine aggregates (RFAs) added to it at both high and normal strengths depicted that compared to HS concrete, NS concrete had greater reductions in its elastic modulus and compressive strength. The different failure mechanisms of NS and HS concrete may help to explain this.

Dabhade (2015): In this experimental investigation, the mechanical strength of concrete is examined after varying the percentage of recycled coarse aggregate added to the original coarse aggregate. Moreover, fly ash is added to increase the quality of concrete in place of cement demonstrated that in ninety days, RAC based concrete with 10% fly ash had a better compressive strength than regular RAC based concrete. This can be the result of fly ash and aged mortar bonding.

2.3 RESEARCH GAP

- Over the years many studies have been take up that have proved that recycled aggregates have different properties in comparison to natural ones. Hence, recycled aggregate concrete exhibits different behavior in various aspects when compared to conventional concrete.
- But as of yet, it is unknown how much natural aggregate may be substituted with recycled aggregate without significantly affecting the concrete's workability.

CHAPTER 3
EXPERIMENTAL INVESTIGATION

3.1 GENERAL

The methodology employed in this study embodies a systematic and meticulously structured approach to scrutinize and analyze the subject matter in question. This section delineates the comprehensive steps undertaken to fulfil the research objectives, thereby ensuring the reliability, validity, and precision of the resultant findings.

Initially, a thorough examination of extant scholarly works, research articles, and pertinent sources was conducted, establishing a robust understanding of the current state of knowledge. This rigorous literature review serves a dual purpose: it facilitates the identification of prevailing research lacunae and furnishes invaluable insights, thereby constructing a contextual framework that underpins the ensuing phases of the investigation.

Upon the identification of these research voids, the subsequent phase involves the acquisition of requisite materials and resources indispensable for experimentation. This phase is characterized by an unwavering commitment to rigor in the selection of appropriate materials, ensuring their alignment with the study's objectives. This meticulous selection process guarantees both the availability and compatibility of materials with the overall research design, thereby reinforcing the methodological integrity of the study.

Testing plays a crucial role in assessing the properties and characteristics of theselected materials. Through a series of well-defined and meticulously conducted tests, the performance, durability, and mechanical properties of the materials are thoroughly evaluated.These tests provide valuable data and insights, forming the basis for subsequent decision- making processes. The subsequent step revolves around mix design, specifically focusing on achieving the desired concrete strength and durability. Meticulous calculations, evaluations,and adjustments are made to determine the optimal proportions of various components, aiming to achieve the desired characteristics and performance of the concrete mixture. Oncethe mix design is finalized, concrete samples are carefully cast and allowed to cure over a specified period, typically 28 days. This period enables concrete to attain its maximum strength and stability. Following the curing process, the samples undergo a battery of tests to evaluate their mechanical properties, including compressive strength, tensile strength, and other relevant factors.

To explore the impact of temperature on the optimized concrete mixture, additional samples are cast and subjected to controlled temperature conditions. These temperature experiments simulate real-world scenarios and provide insights into the behavior and performance of the concrete under varying thermal conditions. The final phase entails a comprehensive analysis of the collected data, where statistical techniques and analytical toolsare employed to derive meaningful conclusions. The results obtained from the tests and experiments are scrutinized, compared, and interpreted to shed light on the performance andbehavior of the concrete mixture.

3.2 WORKING METHODOLOGY

A sequence of tests are performed on the recycled aggregate to ascertain its properties. These include physical and mechanical properties of the aggregate. The results obtained are then compared with those for natural aggregate. The results obtained are also necessary for careful design mix preparation. In this study trial mixes are prepared for M30 grade concrete with varying proportions of recycled aggregates as replacement of natural aggregates. W/C ratio, grade of concrete and cementitious material are kept constant for all the trial mixes. The natural and recycled aggregate used were in air dry condition (natural moisture content). The recycled aggregates used in this study are procured from

IL&FS Construction and Demolition (C&D) Waste Recycling Plant (Burari, Delhi) which has been certified by the Municipal Corporation of Delhi. Five different mixes of concrete are made using recycled aggregate at varying percentages: 0%, 25%, 50%, 75%, and 100% of the total aggregate content. The mix design was followed in the preparation of the concrete mix. The concrete was observed at regular intervals for its characteristics and slump determined. The concrete cube specimens casted afterwards were tested to determine their Compressive Strength at 7 days and 28 days. One question that remains unanswered to this day is how much recycled aggregate may be used overall in concrete to get the necessary qualities of concrete that are comparable to concrete manufactured with natural aggregate. This study's primary goals are to assess the behavior of recycled aggregate concrete (RAC) in its fresh form and calculate the maximum recycled aggregate inclusion ratio needed to produce concrete with the required qualities while utilizing Portland pozzolana cement based on fly ash (PPC). This is determined in terms of workability, strength, density and effective w/c ratio. The study has been carried out using PPC due to its high silica content which makes it cheaper, environmental friendly by reducing CO^2 emissions, as depicted by previous studies it reduces shrinkage.

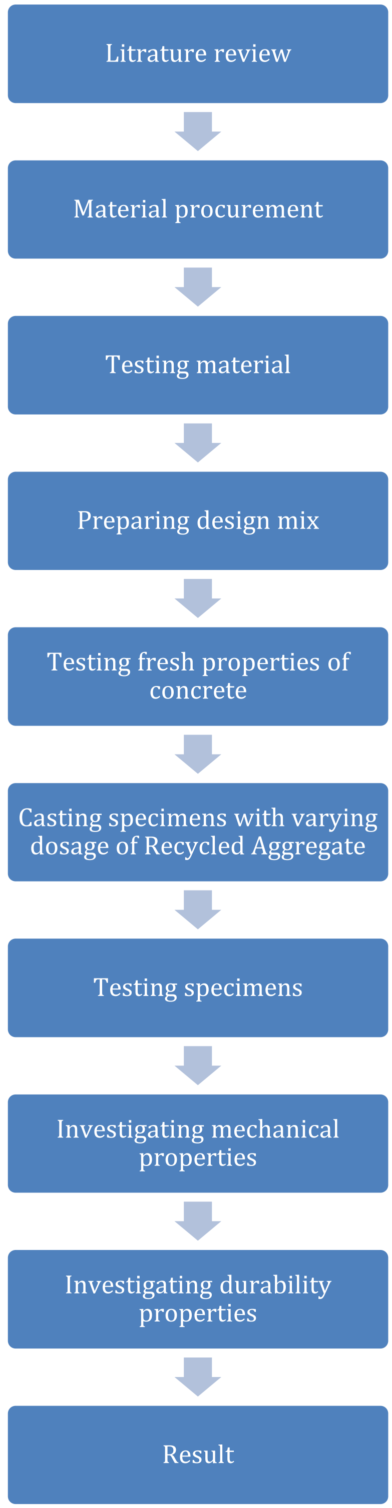

Fig 1:- Working Methodology

MATERIALS USED

Cement: Portland Pozzolana Cement (Ultratech) conforming to IS 1489 (Part 1)

Recycled Aggregate: It is obtained from IL&FS Construction and Demolition (C&D) Waste Recycling Plant (Burari, Delhi)

Admixture: FOSROC Auramix 500 (Superplasticizer) conforming to IS 9103

3.3 PROPERTIES OF MATERIALS

In this experimental programme the physical and mechanical properties of the recycled aggregates and other materials are determined according to the testing programme given by the Bureau of Indian Standard (BIS) Codes and conformed to the specifications.

3.3.1 Sieve Analysis (Recycled Coarse Aggregate)

Nominal Size = 20 mm
Sample taken = 2000 gm.

Observations:

Table 1.1:- Sieve Analysis (RA 20 mm)

Sieve Size(mm)	Mass Retained(gm.)	% Mass Retained	% Cumulative Retained	% Passing
40	0	0	0	100
20	0	0	0	100
10	1907	95.35	95.35	4.65
4.75	84.5	4.25	99.6	0.4

Results

The sieve analysis for coarse aggregate conforms to Table 7 (IS 383)

3.3.2 Flakiness and Elongation Index (Recycled Coarse Aggregate)

Nominal Size = 20 mm

Observations:

Table 1.2:- Flakiness and Elongation (RA 20 mm)

Sieve Size		Weight of 200 Pieces (A)	Passing Weight (B)	X=B/ A*100	Y=A/ ΣA	FI= X*Y/ 100	Weight of Elongated Sample (Z)	Weight of Sample A-B=D	EI=Z/ ΣD*100
Passing	Retained								
20	16	1362	104	7.63	0.519	3.95	78.5	1258	3.24
16	12.5	710	76	18.7	0.270	2.89	259	634	10.7
12.5	10	0.370	23	6.21	0.141	0.87	157.5	347	6.5
10	6.5	0.180	3	1.67	0.0686	1.14	169	177	7
		∑ A = 2622						∑ D=2416	

Flakiness Index = ∑ FI = 7.82%

Elongation Index = ∑ EI = 23.44%

Combined Flakiness and Elongation index = 31.26%

Results:

The combined flakiness and elongation index is 31.26% < 40% confirming to IS 383

3.3.3 Aggregate Impact Value (Recycled Coarse Aggregate)

Nominal Size = 20 mm

Observations:

Total weight of sample taken (A) = 310 gm.

Weight of the sample passing through 2.36 mm sieve (B) = 88.5 gm.

Aggregate Impact Value = 28.54 %

Results:

The aggregate impact value is within the limits conforming to IS 383

3.3.4 Specific Gravity and Water absorption (Recycled Coarse Aggregate)

Nominal Size = 20 mm

Observations:

Weight of sample taken = 2010 gm.

Saturated Surface-Dry Weight (A) = 2052 gm.

Oven-Dry Weight (B) = 1934 gm.

Apparent/Under Water weight (C) = 1203 gm.

True Gravity = 2.28

Apparent Gravity = 2.645

Water Absorption = 6.101%

3.3.5 Sieve Analysis (Recycled Coarse Aggregate)

Nominal Size = 10 mm
Sample taken = 1000 gm.

Observations:

Table 1.3:- Sieve Analysis (RA 10 mm)

Sieve Size(mm)	Mass Retained(gm.)	% Mass Retained	% Cumulative Retained	% Passing
12.5	35.5	3.55	3.55	96.45
10	43.5	4.35	7.9	92.1
4.75	747	74.7	82.6	17.4
2.36	158	15.8	98.4	1.6

Results:

The sieve analysis for coarse aggregate conforms to Table 7 (IS 383)

3.3.6 Flakiness and Elongation Index (Recycled Coarse Aggregate)

Nominal Size = 10 mm

Observations:

Table 1.4:-Flakiness and Elongation (RA 10 mm)

Sieve Size		Weight of 200 Pieces (A)	Passing Weight (B)	X=B/A*100	Y=A/ΣA	FI= X*Y/ 100	Weight of Elongated Sample (Z)	Weight of Sample A-B=D	EI=Z/ ΣD*100
Passing	Retained								
12.5	10	272	32	11.7	66.9	7.82	30	240	8.42
10	6.3	134	18	13.4	33.0	4.42	53	116	14.88
		∑ A = 406						∑ D = 356	

Flakiness Index = ∑ FI = 12.24%

Elongation Index = ∑ EI = 23.30%

Combined Flakiness and Elongation index = 35.54%

Results:

The combined flakiness and elongation index is 35.54% < 40% confirming to IS 383

3.3.7 Aggregate Impact Value (Recycled Coarse Aggregate)

Nominal Size = 10 mm

Observations:

Total weight of sample taken (A) = 306 gm.

Weight of the sample passing through 2.36 mm sieve (B) = 84 gm.

Aggregate Impact Value = 27.45 %

Results:

The aggregate impact value is within the limits conforming to IS 383

3.3.8 Specific Gravity and Water absorption (Recycled Coarse Aggregate)

Nominal Size = 10 mm

Observations:

Saturated Surface-Dry Weight (A) = 500 gm.

Oven-Dry Weight (B) = 467 gm.

Weight of Pycnometer + water + sample (C) = 1840 gm.

Weight of Pycnometer + water = 1553 gm.

True Gravity = 2.182

Apparent Gravity = 2.594

Water Absorption = 7.093%

3.3.9 Sieve Analysis (Recycled Fine Aggregate)

Observations:

Table 1.5:-Sieve Analysis (Recycled Fine Aggregate)

Sieve Size(mm)	Mass Retained(gm.)	% Mass Retained	% Cumulative Retained	% Passing
4.75	27	5.4	5.4	94.6

2.36	36	7.2	12.6	87.4
1.18	77	15.4	28	72
0.600	62	12.4	40.4	59.6
0.300	11	22	62.4	37.6
0.150	12.5	25	87.4	12.6

Results:

The result of sieve analysis for fine aggregate/sand conforms to Table 9 (IS 383)

3.3.10 Specific Gravity and Water absorption (Recycled Fine Aggregate)

Observations:

Saturated Surface-Dry Weight (A) = 542 gm.

Oven-Dry Weight (B) = 500 gm.

Weight of Pycnometer + water + sample (C) = 1843 gm.

Weight of Pycnometer + water (D) = 1553 gm.

True Gravity = 2.09

Apparent Gravity = 2.38

Water Absorption = 8.4%

3.3.11 Cement

Table 1.6:-Properties of Cement

Property	Test Method	Result	Unit	Standard requirement (IS: 12269 2013)

Specific gravity	IS 4031 part 11 1988	3.15	-	-
Standard consistency	IS 4031 (part 4) 1988	29%	%	-
Initial setting time	IS 4031 (part 5) 1988	120	Minutes	Minimum 60 minutes
Final setting time	IS 4031 (part 5) 1988	240	Minutes	Maximum 600 minutes
Compressive strength (7 days)	IS 4031 (part 6) 1988	28	MPa	Minimum 33 MPa
Compressive strength (28 days)	IS 4031 (part 6) 1988	48	MPa	Minimum 43 MPa

3.4 TRIAL MIX FOR M30 GRADE OF CONCRETE

The study employed IS 10262:2019 for mix design, maintaining a consistent w/c ratio of 0.38 for all trial mixes. In the concrete mix, recycled aggregate has been incorporated in percentages of 0%, 25%, 50%,75%, and 100% in place of natural aggregate. Following the preparation of the concrete mix, workability is assessed using the Slump Cone Test conforming to IS 1199, which is conducted every hour for a total of three hours. For the purpose of compression testing, (150 x 150 x 150 mm) concrete cube specimens are created. The cubes are let to cure at room temperature for seven and twenty-eight days, respectively, following casting. The experimental values obtained from this investigation are then used for analyzing the short-term behavior of concrete and establishing relationships between various parameters of concrete mix.

Table 2.1:- Properties (Fresh Aggregate)

Nominal Size	S.P. Gravity	%W.A	Moisture Content
20 mm	2.74	0.3	Nil
10 mm	2.72	0.5	Nil
Fine Agg.	2.54	1.12	3.4

Table 2.2:- Properties (Recycle Aggregate)

Nominal Size	S.P. Gravity	%W.A	Moisture Content
20 mm	2.28	6.1	0.6
10 mm	2.19	7.1	0.81
Fine Agg.	2.09	8.4	7.1

Table 2.3:- Ratio of Coarse Aggregate

Ratio of Coarse Aggregate	
20 mm	0.55
10 mm	0.45

3.4.1 100% Natural Aggregate

Table 3.1:-Trial Mix (NA 100%)

Cement, kg	400
Density of Cement	2.86
Volume of Cement ,m^3	0.1399
W/C Ratio	0.38
Water Content ,kg	152
Volume of Water, m^3	0.152

Admixture ,%(by wt. of cement)	1
Admixture Content ,kg	4
Relative Density of Admixture	1.11
Volume of Admixture ,m^3	0.0036
Rest Volume ,m^3	0.6945
Specific Gravity of Coarse Agg.	2.73
Specific Gravity of Fine Agg.	2.54
Ratio of Coarse Aggregate	0.60
Ratio of Fine Aggregate	0.40
Mass of Coarse Aggregate ,kg	1138
Mass of Fine Aggregate ,kg	706

Table 3.2:-Quantity of Material for Trial Mix

Quantity for 1 m^3		Quantity for 0.035 m^3	Corrected value
Cement, kg	400	14.00	14.00
Water, kg	152	5.32	4.93
20 mm, kg	626	21.90	21.83
10 mm, kg	512	17.92	17.83
Sand. kg	706	24.70	25.24
Admixture, kg	4.00	0.140	0.140
Total	2399	83.98	83.98

3.4.2 25% Recycled Aggregate and 75% Natural Aggregate

Table 3.3:-Trial Mix (NA 75% & RA 25%)

Cement, kg	400
Density of Cement	2.86
Volume of Cement , m^3	0.1399
W/C Ratio	0.38
Water Content ,kg	152
Volume of Water, m^3	0.152
Admixture ,%(by wt. of cement)	1
Admixture Content ,kg	4
Relative Density of Admixture	1.11
Volume of Admixture , m^3	0.0036
Rest Volume , m^3	0.6945
Specific Gravity of Coarse Agg.	2.6
Specific Gravity of Fine Agg.	2.43
Ratio of Coarse Aggregate	0.60
Ratio of Fine Aggregate	0.40
Mass of Coarse Aggregate ,kg	1083
Mass of Fine Aggregate ,kg	675

Table 3.4:-Quantity of Material for Trial Mix

Quantity for 1 m^3		Quantity for 0.035 m^3	Corrected value
Cement, kg	400	14.00	14.00
Water, kg	152	5.32	5.657
20 mm, kg(Fresh)	447	15.64	15.59
10 mm, kg(Fresh)	366	12.80	12.736

Sand, kg(Fresh)	506	17.72	18.124
20 mm, kg(Recycled)	149	5.21	4.924
10 mm, kg(Recycled)	122	4.27	4.002
Sand, kg(Recycled)	169	5.91	5.834
Admixture, kg	4.00	0.140	0.140
Total	2315	74.96	74.96

3.4.3 50% Recycled Aggregate and 50% Natural Aggregate

Table 3.5:-Trial Mix (NA 50% & RA 50%)

Cement, kg	400
Density of Cement	2.86
Volume of Cement , m^3	0.1399
W/C Ratio	0.38
Water Content ,kg	152
Volume of Water, m^3	0.152
Admixture ,%(by wt. of cement)	1
Admixture Content ,kg	4
Relative Density of Admixture	1.11
Volume of Admixture , m^3	0.0036
Rest Volume , m^3	0.6945
Specific Gravity of Coarse Agg.	2.49
Specific Gravity of Fine Agg.	2.315
Ratio of Coarse Aggregate	0.60
Ratio of Fine Aggregate	0.40

Mass of Coarse Aggregate ,kg	1038
Mass of Fine Aggregate ,kg	643

Table 3.6:-Quantity of Material for Trial Mix

Quantity for 1 m^3		Quantity for 0.035 m^3	Corrected value
Cement, kg	400	14.00	14.00
Water, kg	152	5.32	6.343
20 mm, kg(Fresh)	447	15.64	9.96
10 mm, kg(Fresh)	366	12.80	8.13
Sand, kg(Fresh)	506	17.72	11.506
20 mm, kg(Recycled)	149	5.21	9.40
10 mm, kg(Recycled)	122	4.27	7.650
Sand, kg(Recycled)	169	5.91	11.10
Admixture, kg	4.00	0.140	0.140
Total	2237	78.28	78.28

3.4.4 75% Recycled Aggregate and 25% Natural Aggregate

Table 3.7:-Trial Mix (NA 25% & RA 75%)

Cement, kg	400
Density of Cement	2.86
Volume of Cement , m^3	0.1399
W/C Ratio	0.38
Water Content ,kg	152
Volume of Water, m^3	0.152

Admixture ,%(by wt. of cement)	1
Admixture Content ,kg	4
Relative Density of Admixture	1.11
Volume of Admixture , m^3	0.0036
Rest Volume , m^3	0.6945
Specific Gravity of Coarse Agg.	2.36
Specific Gravity of Fine Agg.	2.20
Ratio of Coarse Aggregate	0.60
Ratio of Fine Aggregate	0.40
Mass of Coarse Aggregate ,kg	983
Mass of Fine Aggregate ,kg	611

Table 3.8:-Quantity of Material for Trial Mix

Quantity for 1 m^3		Quantity for 0.035 m^3	Corrected value
Cement, kg	400	14.00	14.00
Water, kg	152	5.32	6.95
20 mm, kg(Fresh)	135	4.73	4.71
10 mm, kg(Fresh)	111	3.87	3.85
Sand, kg(Fresh)	153	5.35	5.472
20 mm, kg(Recycled)	406	14.20	13.420
10 mm, kg(Recycled)	332	11.62	10.89
Sand, kg(Recycled)	458	16.04	15.83
Admixture, kg	4.00	0.140	0.140
Total	2151	75.27	75.27

3.4.5 100% Recycled Aggregate

Table 3.9:-Trial Mix (RA 100%)

Cement, kg	400
Density of Cement	2.86
Volume of Cement , m^3	0.1399
W/C Ratio	0.38
Water Content ,kg	152
Volume of Water, m^3	0.152
Admixture ,%(by wt. of cement)	1
Admixture Content ,kg	4
Relative Density of Admixture	1.11
Volume of Admixture , m^3	0.0036
Rest Volume , m^3	0.6945
Specific Gravity of Coarse Agg.	2.23
Specific Gravity of Fine Agg.	2.09
Ratio of Coarse Aggregate	0.60
Ratio of Fine Aggregate	0.40
Mass of Coarse Aggregate ,kg	929
Mass of Fine Aggregate ,kg	581

Table 3.10:-Quantity of Material for Trial Mix

Quantity for 1 m^3		Quantity for 0.035 m^3	Corrected value
Cement, kg	400	14.00	14.00
Water, kg	152	5.32	7.487
20 mm, kg(Recycled)	511	17.89	16.906
10 mm, kg(Recycled)	418	14.64	13.72
Sand, kg(Recycled)	581	20.32	20.05
Admixture, kg	4.00	0.140	0.140
Total	2066	72.31	72.31

CHAPTER 3

RESULTS

4.1 COMPRESSIVE STRENGTH

The test results for compressive strength are displayed in tabular form below. After seven and twenty-eight days of curing, respectively, the average compressive strength has been established. Additionally, the fluctuation in concrete strength as the amount of recycled aggregate added varies as depicted in the figure below. The results show that when the proportion of recycled aggregate replacing natural aggregate rises, the compressive strength continues to decline. Poon et al. claim that the weak mechanical bond between the recycled aggregate and cement paste at higher moisture levels is the cause of this strength loss. Recycled aggregate loses compressive strength because more water is needed to soak it and maintain the same w/c ratio.

According to Vázquez et al., compressive strength is lost by over 20% when 100% natural aggregates are substituted, and by roughly 2–15% when a 50% replacement ratio is used. Etxeberria et al. also noted a 20–25% decrease in compressive strength while maintaining the same w/c ratio and cement quantity.

According to the compression test results, there are losses of 17.32% for 100% replacement, 13.82% for 50% substitution, and no loss for 25% substitution, which is in line with the findings of Vázquez et al. and Etxeberria et al.

Table 4.1:-Compressive Strength at 7 Days (NA100%)

S.no	Weight (gm.)	Area (mm^2)	Load (kN)	Compressive Strength (N/mm^2)
1	8216	150X150	641.0	28.5
2	8006	150X150	703.0	31.2
3	8132	150X150	515.0	26.8
Average Compressive Strength (N/mm^2)				28.8

Table 4.2:-Compressive Strength at 28 Days (NA100%)

S.no	Weight (gm.)	Area (mm^2)	Load (kN)	Compressive Strength (N/mm^2)
1	8196	150X150	1110.0	49.3
2	8210	150X150	956.0	42.5
3	8172	150X150	930.0	41.3
Average Compressive Strength (N/mm^2)				44.3

Table 4.3:-Compressive Strength at 7 Days (NA75% & RA25%)

S.no	Weight (gm.)	Area (mm^2)	Load (kN)	Compressive Strength (N/mm^2)
1	7924	150X150	700.0	31.1
2	7960	150X150	657.0	29.2
3	7976	150X150	656.0	29.2
Average Compressive Strength (N/mm^2)				29.8

Table 4.4:-Compressive Strength at 28 Days (NA75% & RA25%)

S.no	Weight (gm.)	Area (mm^2)	Load (kN)	Compressive Strength (N/mm^2)
1	7992	150X150	999.0	44.4
2	7964	150X150	975.0	43.3
3	7990	150X150	1102.0	49.0
Average Compressive Strength (N/mm^2)				45.5

Table 4.5:-Compressive Strength at 7 Days (NA50% & RA50%)

S.no	Weight (gm.)	Area (mm^2)	Load (kN)	Compressive Strength (N/mm^2)
1	7820	150X150	719.0	32.0
2	7732	150X150	664.0	29.5
3	7910	150X150	700.0	31.1
Average Compressive Strength (N/mm^2)				30.9

Table 4.6:-Compressive Strength at 28 Days (NA50% & RA50%)

S.no	Weight (gm.)	Area (mm^2)	Load (kN)	Compressive Strength (N/mm^2)
1	7750	150X150	812.0	36.1
2	7621	150X150	872.0	38.8
3	7818	150X150	892.0	39.6
Average Compressive Strength (N/mm^2)				38.2

Table 4.7:-Compressive Strength at 7 Days (NA25% & RA75%)

S.no	Weight (gm.)	Area (mm^2)	Load (kN)	Compressive Strength (N/mm^2)
1	7568	150X150	673.5	29.9
2	7678	150X150	616.8	27.4
3	7609	150X150	634.5	28.2
Average Compressive Strength (N/mm^2)				28.5

Table 4.8:-Compressive Strength at 28 Days (NA25% & RA75%)

S.no	Weight (gm.)	Area (mm^2)	Load (kN)	Compressive Strength (N/mm^2)
1	7635	150X150	987.0	43.86
2	7630	150X150	803.0	35.7
3	7701	150X150	769.0	34.2
Average Compressive Strength (N/mm^2)				37.9

Table 4.9:-Compressive Strength at 7 Days (RA 100%)

S.no	Weight (gm.)	Area (mm^2)	Load (kN)	Compressive Strength (N/mm^2)
1	7401	150X150	623.0	27.7
2	7409	150X150	644.0	28.6
3	7382	150X150	610.0	27.1
Average Compressive Strength (N/mm^2)				27.8

Table 4.10:-Compressive Strength at 28 Days (RA 100%)

S.no	Weight (gm.)	Area (mm^2)	Load (kN)	Compressive Strength (N/mm^2)
1	7265	150X150	801.0	35.6
2	7390	150X150	846.0	37.6
3	7322	150X150	830.2	36.9
Average Compressive Strength (N/mm^2)				36.7

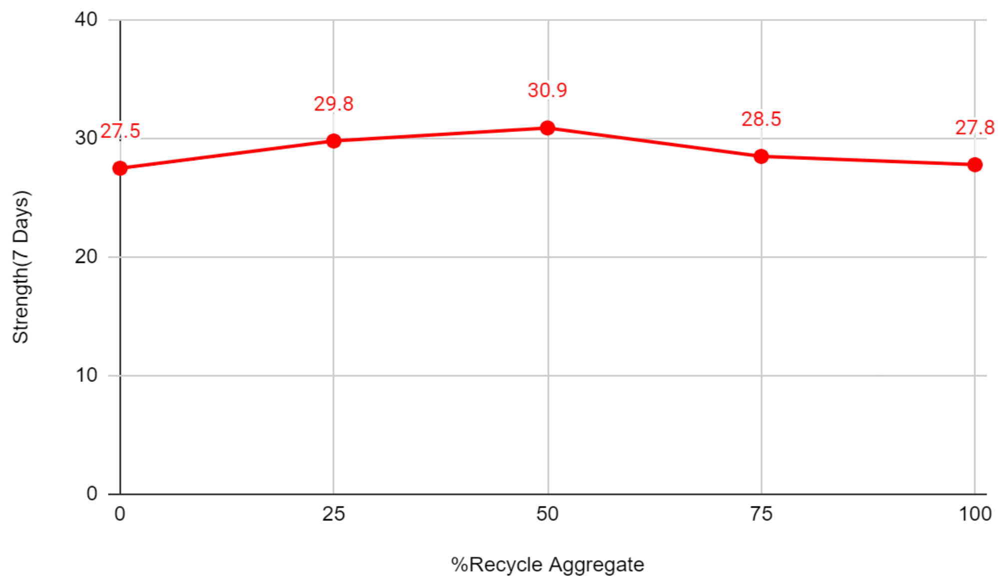

Fig 2:- Graph (Compressive Strength (7 Days) Vs %Recycled Aggregate)

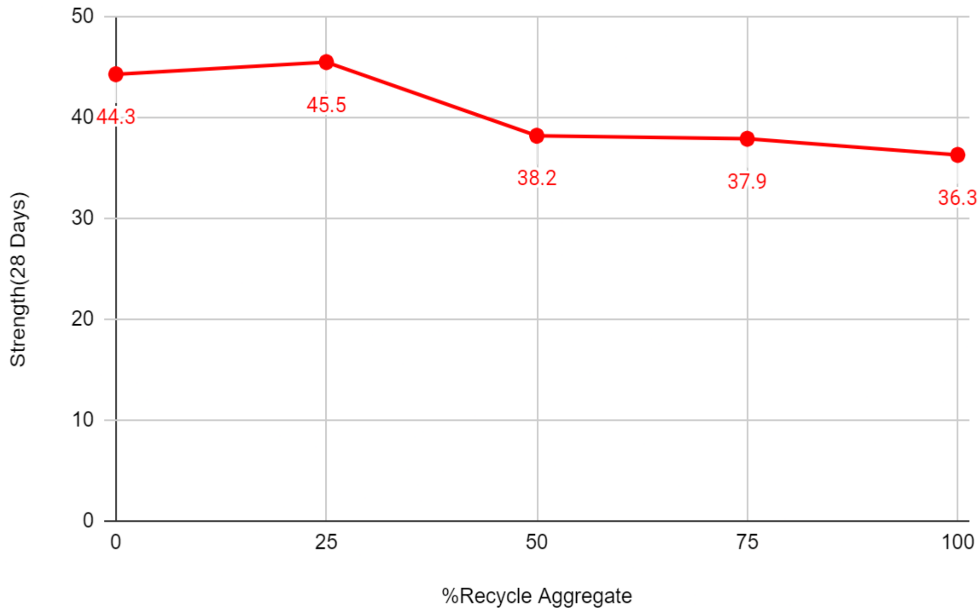

Fig 3:- Graph (Compressive Strength (28 Days) Vs %Recycled Aggregate)

4.2 EFFECTIVE WATER/CEMENT RATIO

As the percentage of recycled aggregate in the concrete mix grows, more water is needed to saturate the aggregate in order to maintain the same w/c ratio for different incorporation ratios. Additionally, the strength of concrete diminishes as the effective w/c ratio rises. The table below shows the effective w/c ratios for incorporating recycled aggregate.

Table 5:-Effective W/C Ratio

%Recycled Aggregate	Effective (W/C Ratio)
0	0.35
25	0.40
50	0.45
75	0.49
100	0.53

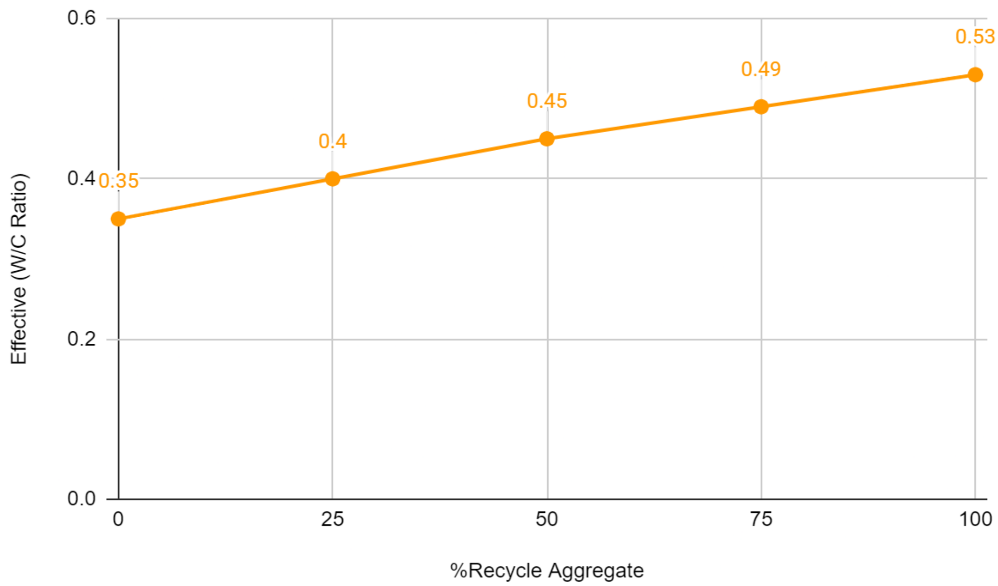

Fig 4:- Graph (Effective (W/C Ratio) Vs %Recycled Aggregate)

4.3 WORKABILITY

The workability for various mixes prepared was determined by slump cone test at an interval of 1 hour for a total of 3 hours. The results are given below in the table.

Workability for freshly prepared concrete mix (Initial Slump) was determined and the results showed a decreasing trend initially and then an increasing trend as the proportion of recycled aggregate inclusion rises. The addition of recycled aggregate, which is more angular and flaky in shape, together with Superplasticizer's reduced effectiveness and RA's higher rate of water absorption than NA are the causes of the mix's first decline in workability. According to Pereira et al., the efficiency of Superplasticizer decreases as recycled aggregate is added to the concrete mix and increases with the percentage of recycled aggregate incorporated.

As observed workability increases as the incorporation ratio of recycled aggregate increases and finally reaches the same value of 100% NA at 100% RA, this is just because the effective water cement ratio has increased because additional water was added to the mix to compensate for the RA absorbing water.

Table 6.1:-Slump (Initial)

%Recycled Aggregate	Slump(Initial)
0	Collapse
25	175
50	200
75	240
100	Collapse

The results for Slump obtained at 1 hour are given below in the table. As already stated above the decrease in workability is due to decrease in efficiency of Superplasticizer added as incorporation of RA increases. The significant decrease in slump value is also due to the high rate of water absorption by RA. In a usual reference time of 10 minutes, the absorption of coarse and fine RA is about 80-90% of the absorption at 24-h. As depicted by F. Rodrigues et al. that RA has high water absorption during initial instants.

However, as the same w/c ratio has been maintained for various substitution ratios of RA, the extra water added to saturate the RA aggregate causes the concrete to bleed and increases the workability as the incorporation ratio of RA increases.

Table 6.2:-Slump (1 hr.)

%Recycled Aggregate	Slump(At 1hr)
0	210
25	30

50	35
75	175
100	220

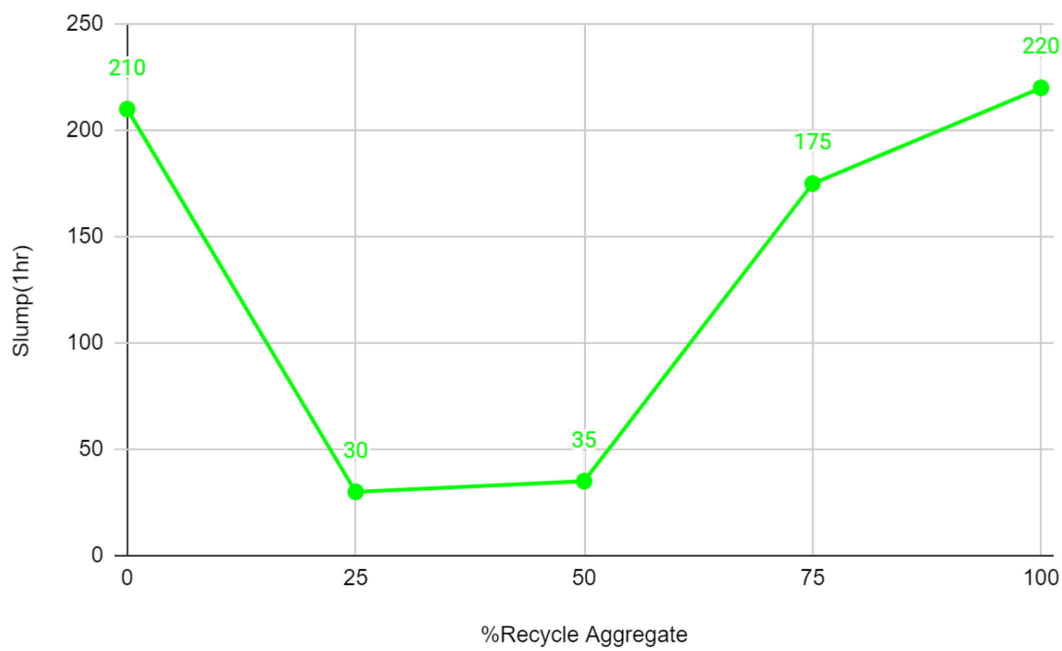

Fig 5:- Graph (Slump (1hr) Vs %Recycled Aggregate)

As the slump values at 2 hour and 3 hour indicate that the workability nearly drops to zero. This happens because there is no longer any free water in the mix, which decreases the slump value, as a result of the extra water that was added to make up for the RA's increased water absorption, which initially caused the concrete to bleed.

Table 6.3:-Slump (2 hr.)

%Recycled Aggregate	Slump(At 2hr)
0	185
25	0
50	0
75	30
100	50

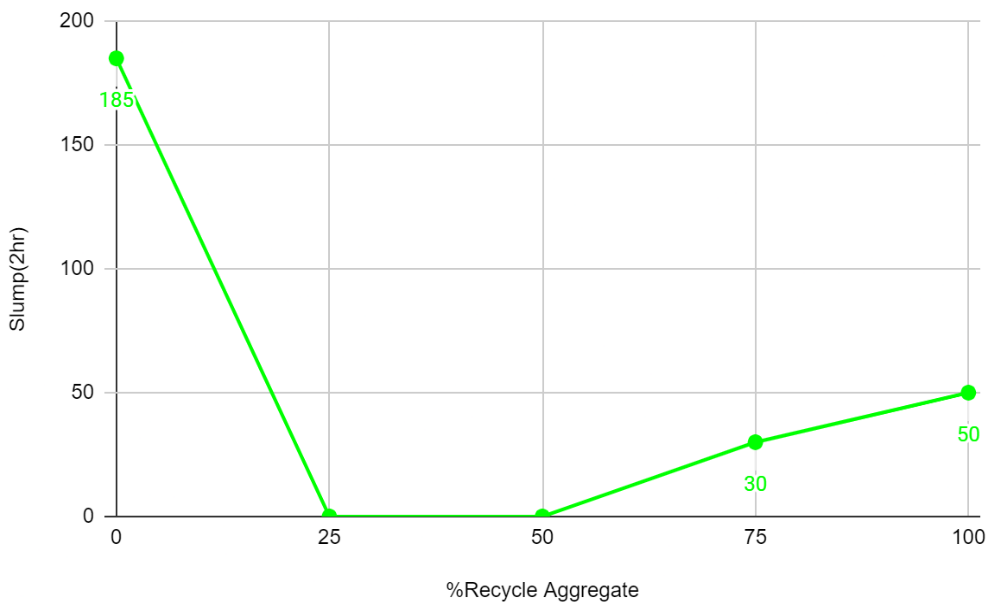

Fig 6:- Graph (Slump (2hr) Vs %Recycled Aggregate)

Table 6.4:-Slump (3 hr.)

%Recycled Aggregate	Slump(At 3hr)
0	150

25	0
50	0
75	0
100	0

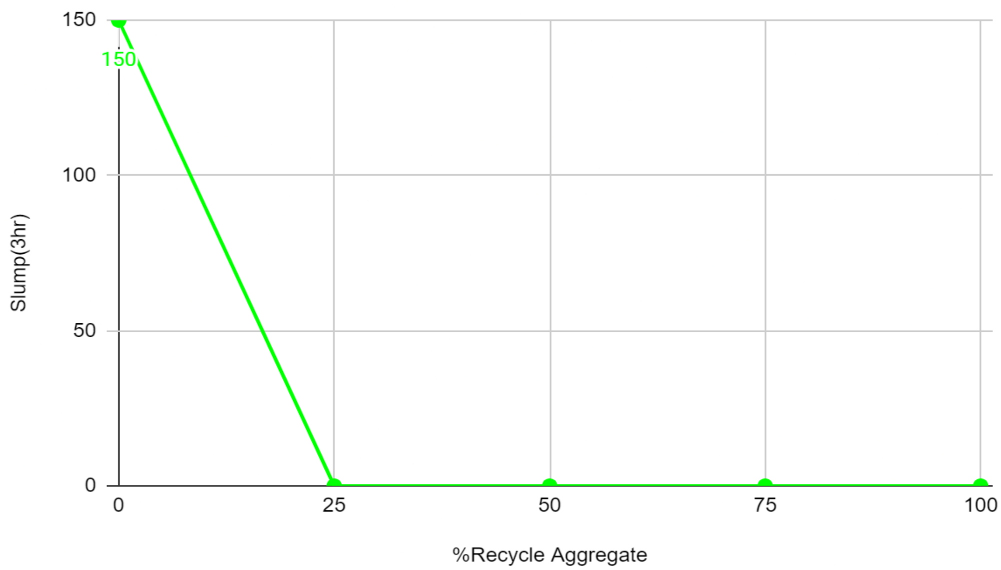

Fig 7:- Graph (Slump (3hr) Vs %Recycled Aggregate)

4.4 BULK DENSITY

The results shown below are for fresh density and dry density of concrete cube specimens initially and after 28 days of curing respectively. The tables given below clearly show a decreasing trend in the density as incorporation ratio of RA increases. This decrease in density can be attributed to high porosity of RA due to presence of lower density residual cement mortar in RA.

Table 7.1:-Wet Density

%Recycled Aggregate	Wet Density(kg/m^3)
0	2536.7
25	2386.7
50	2316.7
75	2246.7
100	2108.7

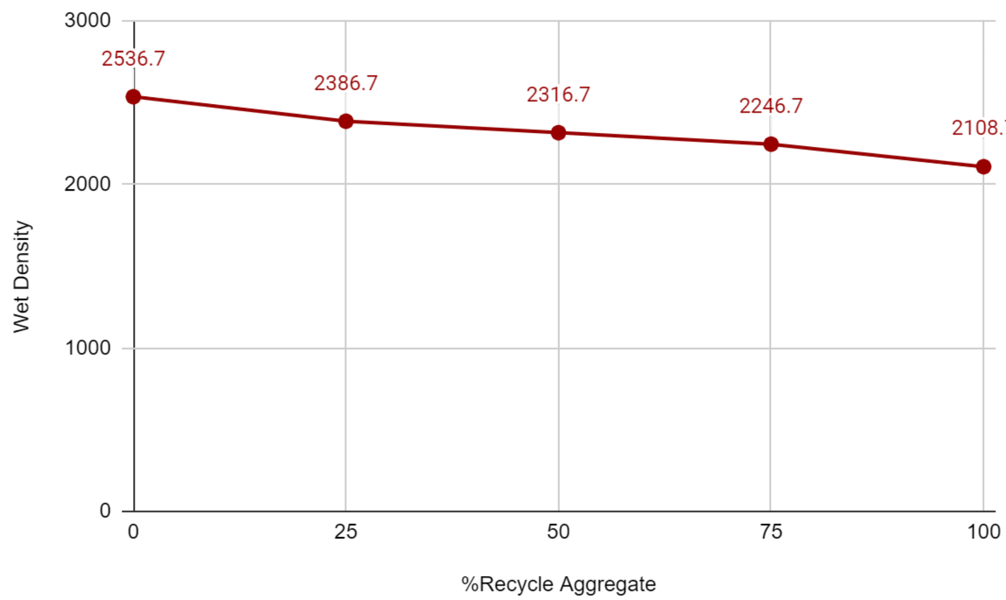

Fig 8:- Graph (Wet Density Vs %Recycled Aggregate)

Table 7.2:-Dry Density

%Recycled Aggregate	Dry Density(kg/m^3)
0	2427.45
25	2365.0

50	2290.2
75	2216.7
100	2162.3

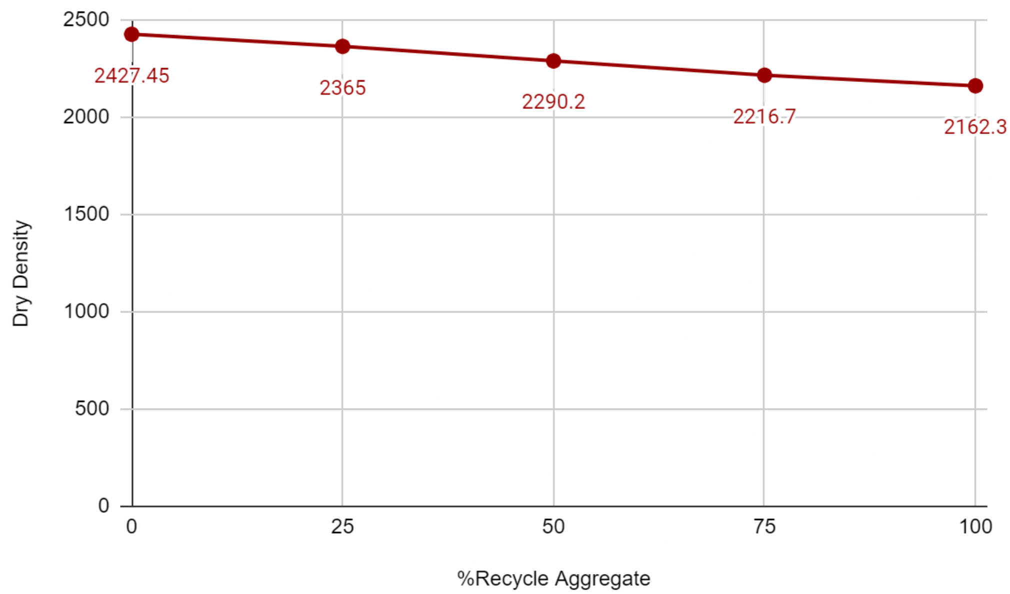

Fig 9:- Graph (Dry Density Vs %Recycled Aggregate)

CHAPTER 5

SUMMARY

5.1 CONCLUSIONS

Outcomes from experimental inquiry lead to the following conclusions:

1. The particle size distribution or gradation of recycled aggregates well corresponds to the specification of fine aggregate and coarse aggregate given by IS Code which means that RA can be well used to substitute NA in concrete.
2. In comparison to NA, the surface of RA with attached cement mortar has a lower specific gravity, more porosity, and a substantially higher capacity for water absorption.
3. As depicted from tests above they have highly irregular shape which results in high flakiness and elongation index. This also might be the reason behind reduction in workability and strength of concrete. This also indicates that concrete produced using these aggregates cannot be used for wearing surfaces.
4. RA have a significantly high impact value as compared to NA but the test results show satisfactory performance during impact loading.
5. Additionally, it is evident that fine RA absorbs more water than coarse RA; this could be because fine RA has a larger surface area.
6. As results are evident the compressive strength of the concrete decreases as the incorporation ratio of RA in concrete increases. However, even after reduction in strength all the batches of concrete achieved the Target Mean Strength.
7. The workability of concrete is greatly impacted by RA's high water absorption capacity. Because of this, more water must be added to the mix in order to compensate for RA's saturation, which initially causes the concrete to bleed.
8. RA has a higher rate of water absorption during initial instants than NA which reduces the workability more rapidly as time progresses.
9. The concrete’s bulk density is directly proportional to the particle density of

aggregate which means the concrete has a bulk density when RA has a high particle density.

10. Generally, workability and strength are the two main properties that consumers demand for construction activities. This investigation clearly demonstrates that RA can be fully used to replace NA in concrete in terms of workability and strength for small scale constructions.
11. The results also depict that concrete mix with 100% incorporation ratio of RA exhibits high workability up to 1 hour and satisfactory workability up to 2 hour which means there would be sufficient time for transportation of the mix.

5.2 Social Impact

The current demand for natural aggregates has put strain on natural resources and depleting them. Thus environmental protection by waste management and recycling is the need of the hour. Current statistics forecast the demand of construction aggregate to rise by 2.6% every year to reach 49.5 billion metric tons till 2025 with Asia and Pacific being the largest consumers

At present India produces about 25.75 MT of construction and demolition waste annually. As per data from reports provided by Central Pollution Control Board in India, of the 50 million tons of solid waste produced 15.5-million-ton waste is being generated by the construction industry alone and of this about 3% is being utilized.

In India the total demand for aggregates in the year 2019 was 5075 million metric tons and of this demand only 3-4% was satisfied with recycled aggregate. This proves that there is a tremendous scope to reduce construction costs and utilize and manage construction waste effectively.

As said earlier recycled aggregate is the material of future. Utilizing recycled aggregates as an alternative to natural aggregates will surely have wide ranging impacts on the society in long run. Substitution of natural aggregates by recycled aggregates will not only promote sustainable development practices but also advocate for environmental preservation. Recycled aggregates will accomplish two goals with one action which are making construction economical and solving the major problem of Construction and Demolition waste disposal.

Utilizing recycled aggregates results in a significant cost reduction by about 35-41% and CO^2 emission by about 25-28% due to discarding at public/private disposal facilities.

5.3 Future Scope

The field of RAC offers a wealth of opportunities for additional research and study. Of particular interest is the long-term behavior of 100% recycled aggregate concrete, which may include characteristics like durability, drying shrinkage, and elastic qualities. With the addition of fibers or any other material, the emphasis can also be changed to high strength recycled aggregate concrete for huge projects. Enhancing the workability and investigating novel facets of pumpable concrete is an additional recommendation.

5.4 References

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