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An Experimental Investigation On Strength Properties of Concrete with Partial Replacement of Cement and Coarse Aggregate by Silica Fume and Recycled Aggregate

D. Sreehari Rao*[1], Golla Madhu[2]

*[1]Assistant Professor, Department of Civil Engineering, SVU College of Engineering, Tirupati, Andhra Pradesh, India

[2]MTech Scholar, Department of Civil Engineering, SVU College of Engineering, Tirupati, Andhra Pradesh, India

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ABSTRACT

Construction-Demolition waste is the major part of solid waste, which contributes almost 30% of solid waste every year and creates lot of environmental issues. Now a days building material crisis in construction industry also increasing every year. Use of Construction-Demolition waste in construction industry would be the sustainable solution for this problem. Use of C&D waste in concrete have so many advantages in construction industry and also solve lot of environmental problems and also increase the economic contribution of construction industry in countries development. Use of C&D waste in concrete would lead to eco-friendly concrete with sustainable development. The main moto of the present project is to use Construction demolition waste-Recycled aggregates in concrete without compromising the properties of concrete. The physical properties such as specific gravity, water absorption and sieve analysis of construction demolition waste-Recycled aggregates and natural aggregates are investigated and the natural aggregates are replaced by Construction demolition waste-Recycled aggregates in concrete in different proportions (i.e., 0%, 20%, 40% ,60%,80% and 100%). The properties of hardened concrete such as compressive strength, split-tensile strength, flexural strength and Non-destructive tests (Rebound Hammer, Ultrasonic Pulse velocity test) is investigated and compared with the conventional control concrete. The results are concluded that the strength properties of concrete won't affected up to 40% replacement of Construction demolition waste Recycled aggregates.

Key words: C&D Waste, Recycled Coarse Aggregate, Properties of Hardened Concrete

I. INTRODUCTION

Construction and Demolition (C&D) waste consists of:

- building materials,
- debris, and rubble resulting from construction,
- repair, renovation, and demolition of unused and completed design period structures such as residential houses, bridges, huge water tanks, roads, dams, massive building structures

Other infrastructure C&D waste usually comprises inert and non-biodegradable material such as concrete, brick aggregates, tiles, plastic, wood, glass, metals, excavated soil and rock particles, etc..

The quantities and composition of C&D waste may vary according to the type of structure and the scale of construction, demolition, or renovation activities. According to the Building Material Promotion Council (BMPTC),2020 India generates an estimated 150 million tonnes of construction and demolition (C&D) waste every year. But the official recycling capacity is a meagre 6,500 tonnes per day (TPD) -- just about 1 per cent. C&D waste contributes about 30 to 40% of the total solid waste generated worldwide.

Recycled demolished concrete are comprised of crushed, graded inorganic particles processed from the materials that have been used in the constructions and demolition debris. These materials are generally from buildings, roads, bridges. With the sharp development of construction and increase of people's awareness of environmental protection, waste control and management become one of the great challenges of modern society for the mission of sustainable development.

Construction and demolition (C&D) waste constitutes one major portion of total solid waste produced in the world, including demolished concrete, bricks, and masonry, limestone, ceramic and other materials. Structures include buildings of all types, both residential and non-residential, as well as roads and bridges. Components of C&D debris typically include concrete, asphalt, E-waste, wood, metals, gypsum wallboard and roofing. Main components of CDW are generally brick, concrete, wood, and ceramic tile. Except for soil and fine aggregates, the predominant materials, especially in buildings from the last century, are brick and cement block. Concrete and masonry waste can be recycled by sorting, crushing and sieving into recycled aggregate.

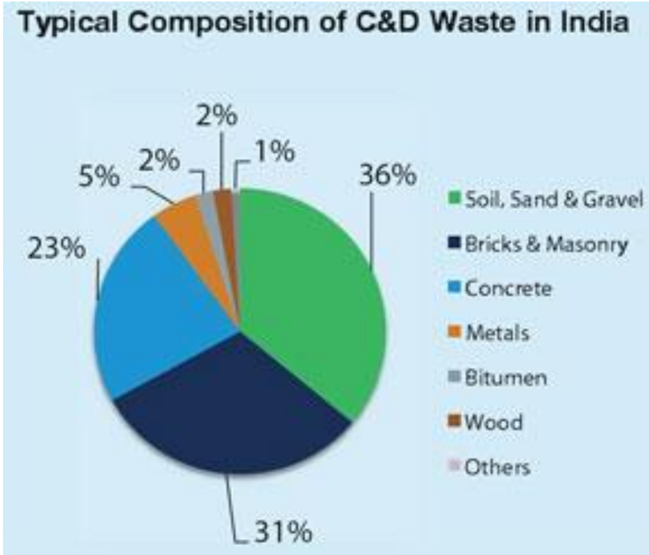


Figure 1: Typical Composition of C&D waste in India

II. LITERATURE REVIEW

1. **Zainab AbdulrdhaThoeny (2022)**

- Natural coarse aggregate can be substituted with recycled concrete aggregate.
- The efficiency of RCA has an impact by the adhered mortar on the aggregate surface.

2. **Ahmad Sarhan,Siddarth Shah. (2021)**

- RCA has various characteristics than NA because of the attached RCA mortar.
- The RCA's Specific Gravity was low;the RCA absorption was increased.
- The air in the old mortar attached to the RCA is even higher than the NA.

3. **Keila Robalo, Hugo Costa, Ricardo do Carmo and Eduardo Júlio et al. (2020)**

has made efforts to develop Innovative eco-efficient concrete to reduce the environmental impact related to construction and demolition waste, extraction of natural aggregates and CO2 emissions of Portland cement. Several concrete mixtures with low cement content and construction and demolition waste (CDW) recycled aggregates named as “low cement recycled aggregate concrete” (LCRAC), were developed. An optimized matrix of low cement concrete was developed and high replacement volume rates of CDW aggregates (43–80%) were considered, leading to different LCRAC, to evaluate their influence on concrete properties.They demonstrated conclusion of reduced and optimized low cement dosage (until 175 kg/m3) and significant replacement rate of natural by CDW aggregates (up to 60%) for structural purposes, with good workability and high eco-efficiency performance allowing the strength reduction up to 30% only. They resulted the progressive replacement rate of natural aggregates by different CDW aggregates, from 43 to 80% leads to the following decreases: between 26% and 48% in the young’s modulus, between 28% and 46% in the compressive strength; between 6% and 33% in the splitting tensile strength and between 17% and 34% in the flexural strength. Correlations with R2 higher than 0.99 were obtained between the young’s modulus and the W/B ratio.

4. Ayser J Ismail, Khaleel H. Younis, George Taylor (2020)

As a result of its high capacity to absorb water, high porosity and its rough surface, recycled aggregate (coarse) diminish the workability of concrete. The inclusion of SF increases this diminish in the workability of the RAC due to the high surface area of its particles. The decline in the workability can reach 50%.

Replacing OPC with Silica Fume possess a beneficial influence on compressive strength, split tensile strength and flexural strength of RCA mixtures. The pozzalonic reaction of the SF particles is the prime reason behind the strength enhancement.

5. Qin Lia, Chunhong Zhang (2017)

This paper investigates the probability distribution characteristics for the compressive strength of concrete with RCA from two different sources. Within the scope of this study, the following conclusions can be drawn: The standard deviation and coefficient of variation of the compressive strength of concrete with different RCAs are only slight higher than that of normal concrete. The normal distribution can be utilized to fit the compressive strength of RAC at 95% confidence level. The distributions for the compressive strength of RAC do not vary much from that of normal concrete with similar strength, inspection of the RCA from different sources.

III.METHODS AND MATERIAL

1. Objectives

The aim of this study was not only to find out utilisation of waste materials on concrete in order to compare them from the economic point of view but also to investigate the feasibility of using materials from deconstructed buildings . It's hoped that the findings of such study will encourage professionals to use second hand components in new buildings/constructions. The objectives of this research are following as-

a. To use of the demolished and construction waste aggregate in the concrete as the recycled coarse aggregate in various percentages 20%, 40%, 60%, 80%, 100% respectively.
b. To study the physical properties of materials used in project by conducting experimental work.
c. To study and compare the mechanical properties (compressive, split tensile and flexural) with conventional concrete.
d. To study the quality of concrete from Non-Destructive Tests (Rebound Hammer & Ultrasonic Pulse Velocity).

2. Materials

a. Cement

The most common cement used is an Ordinary Portland Cement (OPC). The Ordinary Portland Cement of 53 grade (OPC) conforming to IS: 8112-1989 is used. A cement is a binder, a substance used in construction that sets, hardens and adheres to other materials, binding them together Cement is seldom used solely, but is used to bind sand and gravel (aggregate) together.

Figure 2: Cement

TABLE I: PROPERTIES OF CEMENT

Characteristics	Values	IS Standards (IS 12269)
Specific Gravity	3.15	3.10 – 3.15
Fineness (%)	4%	10%
Normal Consistency	31%	25 to 35%
Intial Setting Time	108 (mins)	30mins (min.)
Final Setting Time	416 (mins)	600mins (max.)

b. Silica Fume

Figure 3: Silica Fume

Silica fume is a by-product from the production of elemental silicon or alloys containing silicon in electric arc furnaces. The recommended dosage is 7-10 % of the cement weight is added to the concrete. In this project, silica fume of 10% cement weight is adopted. The properties of silica fume are tabulated below:

TABLE II: PROPERTIES OF SILICA FUME

Properties	Results
Odour	Odourless
Colour	White color powder
Pack Density	0.76 g/cc
PH	6.90
Specific Gravity	2.63
Moisture Content	0.058%

c. Fine Aggregate

Figure 4:Fine Aggregate

Fine aggregates are basically sand got from the land or the marine environment. Fine aggregates generally consist of natural sand or crushed stone with most particles passing through a 4.75mm sieve. Fine aggregate, those fractions from 4.75 mm to 150 microns are termed as fine aggregate. The river sand is be used in combination as fine aggregate conforming to the requirements of IS 383- 1970 The river sand is washed and screened, to eliminate deleterious materials and over size particles.

TABLE III: PROPERTIES OF FINE AGGREGATE

Characteristics	Values
Zone	II
Specific Gravity	2.64
Fineness Modulus	2.74
Bulk Density	1619 Kg/m^3

d. Natural Coarse Aggregate

Coarse aggregate, the fractions from 20 mm to 4.75 mm are used as coarse aggregate. The Coarse Aggregates from crushed Basalt rock, conforming to IS: 383 are to be used. The Flakiness and Elongation Indices were maintained well below 15%, the below table gives the properties of aggregates.The coarse aggregate utilised in this experiment is crushed angular in shape and is 60% of 20mm size and 40% of 12mm size.

Figure 5:Natural Coarse Aggregate

TABLE IV: PROPERTIES OF NATURAL COARSE AGGREGATE

Properties	Test results
Specific gravity	2.63
Water absorption	0.23%
Fineness Modulus	7.15
Bulk density(20mm)	1430Kg/m^3

e. Recycled Coarse Aggregate

Figure 6:Recycled Coarse Aggregate

The waste from the demolition of concrete structures is collected, aggregates are separated as recycled aggregates. The proposed recycled aggregates are used in the concrete mix for this project The recycled aggregates are conformed by means of grading. As per specification 60% of 20 mm and 40% of 10 mm angular recycled aggregates are selected for partial replacement.

The aggregates collected from demolished structures are collected and recycled from recycling plant situated at Thukivakam, Tirupati.

TABLE V: PROPERTIES OF RECYCLED COARSE AGGREGATE

Physical Properties	Values
Water Absorption (%)	2.31
Specific Gravity	2.63
Fineness Modulus	7.02
Bulk Density (Kg/m^3)	1469.8

f. Water

Water available in the structural laboratory has been used for preparation of concrete in the entire experimental program. The quality of water has been tested in the environmental laboratory as per IS standards and it is found suitable for the use. The test results obtained are confirms the permissible values stipulated in the IS 456-2000.The properties of water is tabulated below:

TABLE VI: PROPERTIES OF WATER

Properties	Test Results	Permissible Limits (IS:456-2000)
P^H	7.76	Not less than 6
Chlorides	160 mg/l	500 mg/l
Sulphates	110 mg/l	400mg/l
Total Dissolved Solids	1000 mg/l	2000 mg/l
Organic solids	100 mg/l	200mg/l
Inorganic Solids	900 mg/l	3000mg/l

g. Super-plasticizer

Figure 7: Super-plasticizer

TABLE VII: PROPERTIES OF SUPER-PLASTICIZER

Properties	Test results
Appearance	Light Yellow coloured liquid
P^H	Min. 6.0
Volumetric mass @20⁰C	1.09 kg/lt
Chloride Content	Nil

Super-plasticizer used in this experimental investigation is Polycarboxylic ether (PCE) based polymer with long lateral chains confirmed to IS: 9103-2007).

3. Mix Design

TABLE VIII: MIX PROPORTIONS

Mixture	Control Mix	Mix Ratio
Cement (Kg/m³)	340	1
Fine Aggregate (Kg/m³)	712.3	2.09
Coarse Aggregate (Kg/m³)	1304.5	3.84
Water (Kg/m³)	153	0.45
Super Plasticizer (Kg/m³)	0.36	0.001

TABLE IX: MIX DETAILS OF VARIOUS MIXES

Mix	Mix details
A0	NORMAL CONCRETE (100%)
A1	20% RCA +80% NCA
A2	40% RCA +60% NCA
A3	60% RCA +40% NCA
A4	80% RCA +20% NCA
A5	100% RCA +0% NCA

TABLE X: MIX QUANTITIES

Mixtures	A0	A1	A2	A3	A4	A5
Cement (Kg/m³)	340	306	306	306	306	306
Silica Fume (Kg/m³)	0	34 (10%)	34 (10%)	34 (10%)	34 (10%)	34 (10%)
Coarse Aggregate (Kg/m³)	1304.50	1043.6	782.7	521.8	260.9	0
Replacement of coarse with recycled aggregate (Kg/m³)	0 (0%)	260.9 (20%)	521.8 (40%)	782.7 (60%)	1043.6 80%	1304.50 100%
Fine Aggregate (Kg/m³)	712.18	712.18	712.18	712.18	712.18	712.18
Water (Kg/m³)	153	153	153	153	153	153
Super-Plasticizer (Kg/m³)	0.34 (0.1%)	1.224 (0.4%)	2.448 (0.8%)	3.672 (1.2%)	4.896 (1.6%)	6.12 (2.0%)

IV.EXPERIMENTAL INVESTIGATION

The following are the strength tests which was conducted in the project:

- Compressive strength test
- Split tensile strength test
- Flexural strength test
- Non-Destructive Tests (Rebound Hammer & UPV)

V. RESULTS AND DISCUSSIONS

A. Compressive Strength Test

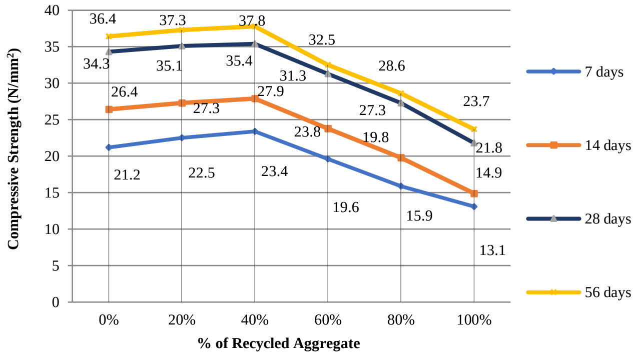


Chart - 1: Compressive Strength of different mixes

From the figure we can notice that, the compressive strength of specimens at the age of 7, 14, 28, 56 days were tested and the results were drawn in graph, from this we can infer that percentage increases in recycled aggregate gives increment in the compressive strength up to 40% replacement and then the compressive strength start decreasing.

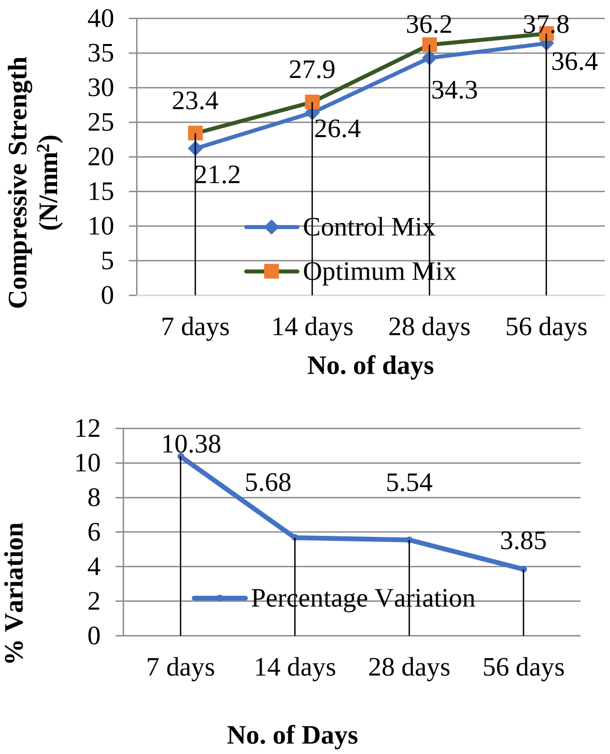


Chart - 2: Compressive Strength for Optimum Mix w.r.t Control Mix & Percentage Variation

From the above graph, we clearly observe that the compressive strength is increased for optimum mix than control mix, and the percentage increase is 10.38%,5.68%,5.54% and 3.85% for 7days, 14days,28 days and 56 days respectively.

B. Split Tensile Strength Test

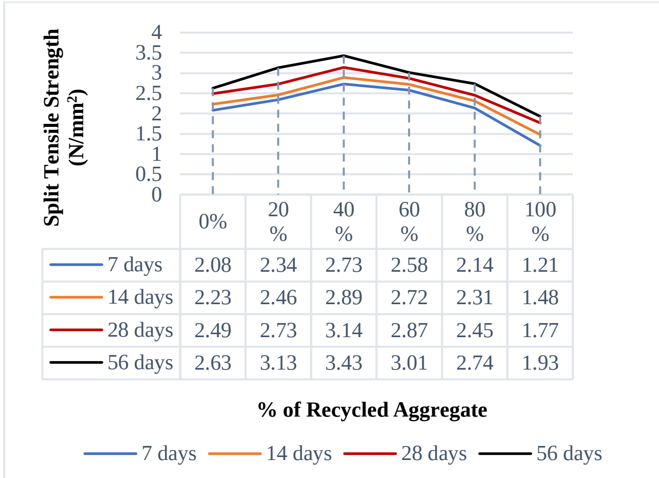


Chart - 3: Split Tensile Strength for different mixes

From the figure we can notice that, the split tensile strength of specimens at the age of 7, 14, 28, 56 days were tested and the results were drawn in graph, from this we can infer that percentage increases in recycled aggregate gives increment in the split tensile strength upto 40% replacement and then the split tensile strength start decreasing.

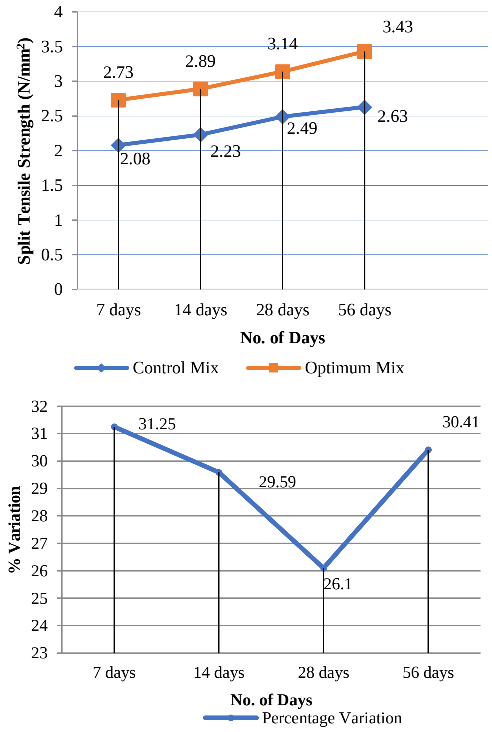
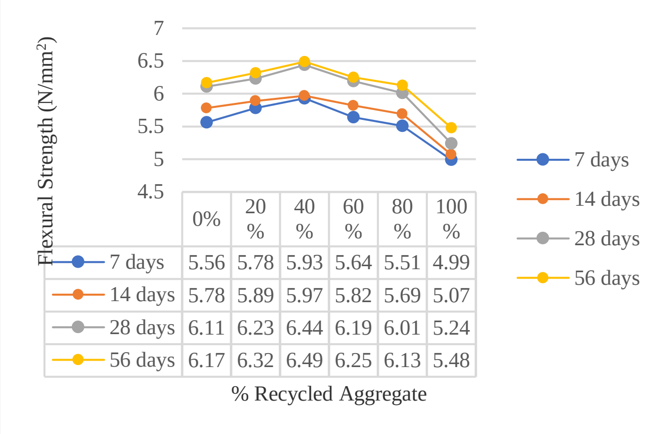


Chart - 4: Split Tensile Strength for Optimum Mix w.r.t Control Mix & Percentage Variation

From the above graph, we clearly observe that the split tensile strength is increased for optimum mix than control mix, and the percentage increase is 31.25%,29,59%,26.1% and 30.41% for 7days, 14days, 28 days and 56 days respectively.

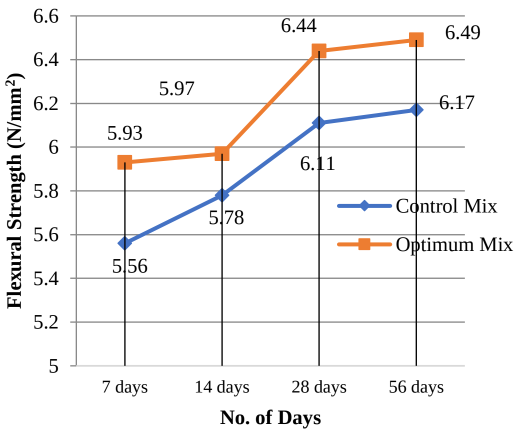
C. Flexural Strength Test



	0%	20 %	40 %	60 %	80 %	100 %
7 days	5.56	5.78	5.93	5.64	5.51	4.99
14 days	5.78	5.89	5.97	5.82	5.69	5.07
28 days	6.11	6.23	6.44	6.19	6.01	5.24
56 days	6.17	6.32	6.49	6.25	6.13	5.48

Chart - 5: Flexural Strength for different mixes

From the figure we can notice that, the flexural strength of specimens at the age of 7, 14, 28, 56 days were tested and the results were drawn in graph, from this we can infer that percentage increases in recycled aggregate gives increment in the flexural strength upto 40% replacement and then the flexural strength start decreasing.



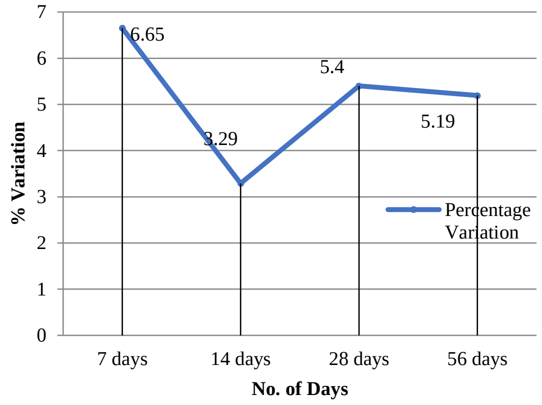


Chart - 6: Flexural Strength for Optimum Mix w.r.t Control Mix & Percentage Variation

From the above graph, we clearly observe that the flexural strength is increased for optimum mix than control mix, and the percentage increase is 6.65%,3.29%,5.4% and 5.19% for7days,14days, 28 days and 56 days respectively.

D. Rebound Hammer Test

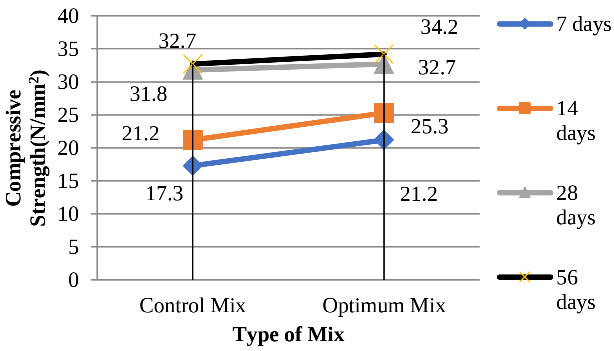


Chart - 7: Compressive Strength from Rebound Number

E. Ultrasonic Pulse Velocity Test

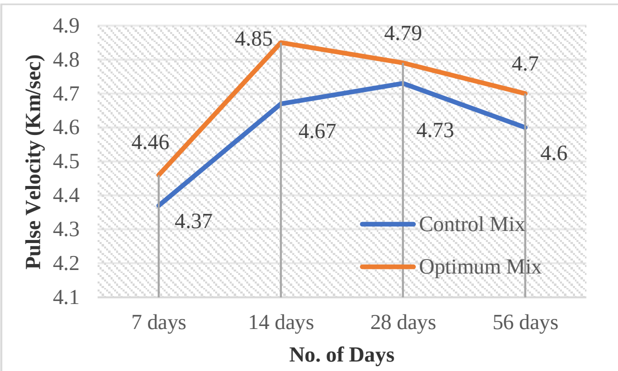


Chart - 8: Quality of concrete from UPV

From the above results the concrete quality for control and optimum mix comes under Good to Excellent Category.

F. Comparision between Destructive and Non-Destructive Tests for Control Mix

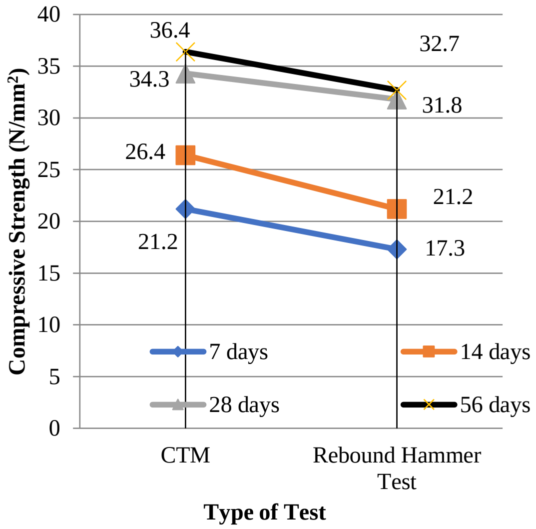


Chart - 9: Comparision of Compressive Strength for Control Mix

G. Comparision between Destructive and Non-Destructive Tests for Optimum Mix

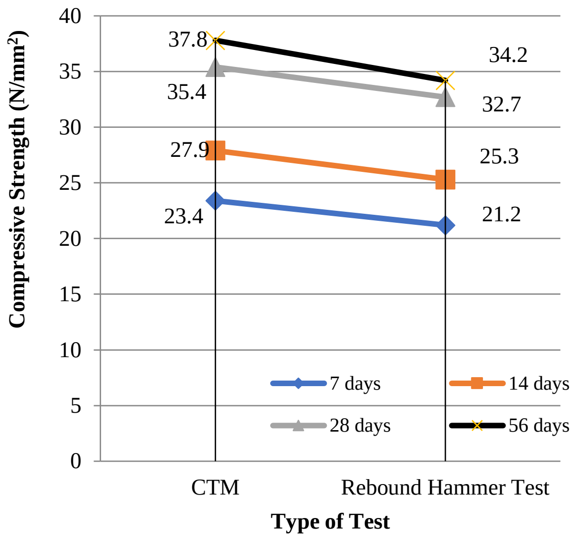


Chart - 10: Comparision of Compressive Strength for Optimum Mix

VI.CONCLUSIONS

Based on limited experimental investigation concerning the strength tests i.e., compression, split tensile and flexural strength and non-destructive tests, the following observations are observed regarding the resistance of replacement done with RCA to NCA in M25 concrete:

1. As the percentage of recycled aggregate increases in concrete, the strength of concrete is slightly increases up to optimum and after optimum it decreases far away from the control mix.
2. The specimens up to 40 % replacement of recycled aggregate attains required strength as per IS code. So, the optimum mix is obtained at 40% replacement of recycled aggregate.
3. Workability of concrete containing recycled aggregate is significantly decreased because of high porosity and low density of recycled aggregate requires a large amount of water to achieve required slump. So, to achieve the required workability and slump, super-plasticizer of various concentrations i.e., 0.1%,0.4%,0.8%,1.2%,1.6% and 2.0% for A0, A1, A2, A3, A4 and A5 mixes respectively.
4. The mechanical properties of concrete i.e., Compressive Strength, Split Tensile Strength and Flexural Strength achieved slightly higher values than control mix upto optimum and decreases far away from control mix after optimum, irrespective of curing period.
5. The compressive strength is increased for optimum mix than control mix, and the percentage increase is 10.38%,5.68%,5.54% and 3.85% for 7days,14days, 28 days and 56 days respectively.
6. The split tensile strength is increased for optimum mix than control mix, and the percentage increase is 31.25%,29,59%,26.1% and 30.41% for 7days,14days, 28 days and 56 days respectively.

7. The flexural strength is increased for optimum mix than control mix, and the percentage increase is 6.65%,3.29%,5.4% and 5.19% for 7days,14days, 28 days and 56 days respectively.
8. From the Rebound Number for control mix and optimum mix, the concrete achieved Fair to Good quality.
9. From the Ultrasonic Pulse Velocity for control mix and optimum mix, the concrete achieved Good and excellent quality.
10. The idea of reusing the waste material is very exciting and encouraging, which will minimize the under mining, exploitation of earth crust and green forest cover.

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