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Experimental Study on Strength and Durability Characteristics of Fibre Reinforced Recyled Aggregate Concrete

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ABSTRACT
The use of recycled aggregates in concrete opens a whole new range of possibilities in the reuse of materials in the building industry. This could be an important breakthrough for our society in our endeavours towards sustainable development. The trend of the utilisation of recycled aggregates is the solution to the problem of an excess of waste material, not forgetting the parallel trend of improvement of final product quality. The utilisation of waste construction materials has to be related to the application of quality guarantee systems in order to achieve suitable product properties. Therefore, the complete understanding of the characteristics of new material becomes so important in order to point out its real possibilities.
My thesis aimed to focus on the possibility of structural use of recycled aggregate concrete by studying the mechanical properties and durability aspects of conventional aggregate concrete, recycled aggregate concrete and fibre reinforced recycled aggregate concrete.
Keywords: Recycled Aggregate Concrete; Fibre Reinforced Recycled Aggregate Concrete, Strength Properties; Durability Characteristics; Non-Destructive Assessment.

I. INTRODUCTION

For thousands of years, the improvement of the quality of life has been the indicator of any developed society. This indicator has always been associated to the presence of elements and infrastructures, which facilitate the development of daily activities without taking into account the impact that they could have. History has taught us that society has made the recovery and use of rejected elements a habitual practice. Numerous civilisations have reused building materials of earlier civilizations of their own destroyed architecture (either through war or natural causes) to construct new buildings. The remains of ruined Romanesque churches supplied the stone for various farmhouses.

Construction and demolition waste is not dangerous from an environmental point of view, the control of this becomes indispensable from the moment that statistics refer to the waste's volume approaching an unsustainable level. According to information obtained from Central Pollution Control Board, the annual quantityof construction and demolition waste in India is approximately 120,00,000 tons. Management of such high quantum of waste puts enormous pressure on solid waste management system. Quantity of different constituents of waste that arise from Construction Industry in India is estimated as follows:

TABLE 1Constituent Quantity Generated in million Tons per annum

Soil, Sand & gravel	4.20 to 5.14
Bricks & Masonry	3.60 to 4.40
Concrete	2.40 to 3.67
Metals	0.60 to 0.73
Bitumen	0.25 to 0.30
Wood	0.25 to 0.30
Others	0.10 to 0.15

OBJECTIVES

The present work is aimed to analyse and give technical specifications on strength characteristics of Recycled Aggregate Concrete with and without fibres. The main objective of the experimental investigation is to assess the utility of recycled coarse aggregates in the production of structural concrete.

II. Recycled Aggregates-Review

2.1 INTRODUCTION

Recycled aggregate is a stone or gravel which has been previously used in construction and has been crushed and separated from contaminants. Concrete is a vital component of everyday life and is being extensively used for all types of structures, right from the smallest dwelling to a huge sky scrapers or a bridge. So every day millions and millions of cubic meters of concrete is being made and used all over the world. Of the three basic components of the concrete, only cement is manufactured and the aggregates both fine and coarse are obtained naturally. This has resulted in large scale quarrying of rocks for obtaining coarse aggregates and removal of sand from river beds for fine aggregates. The reutilization of these aggregates will conserve both the natural aggregates and landfills from the excess construction and demolished waste material.

2.2 APPLICATIONS OF RECYCLED AGGREGATES

Traditionally, the application of recycled aggregate is used as landfill. Nowadays, the applications of recycled aggregate in construction areas are wide. The applications are different from country to country.

1) Granular Base Course Materials: Recycled aggregate are used as granular base course in the road construction. It was stated that recycled aggregate had proved to be better base course material than conventional aggregate when used as granular base course in roads construction. They also found that when the road is built on the wet sub grade areas, recycled aggregate will stabilize the base and provide an improved working surface for pavement structure construction.

2) Embankment Fill Materials: Recycled aggregate can be used in embankment fill. The reason for being able to use in embankment fill is same as it is used in granular base course construction. The embankment site is on the wet sub grade areas. Recycled aggregate can stabilize the base and provide an improved working surface for the remaining works.

3) Backfill Materials: Recycled aggregate can be used as backfill materials. Norwegian Building Research Institute mentioned that recycled concrete aggregate can be used as backfill materials in the pipe zone along trenches after having testing in laboratory.
The other general applications are
Ø Lean-concrete and bituminous concrete
Ø Low quality stabilization and filler material
Ø Thermal reservoirs
Ø New concrete for
a. pavements
b. shoulders
c. median barriers
d. sidewalks
e. curbs and gutters
Ø Soil-cement pavement bases
Ø Neutralizing beds and filtration beds
Ø Sound barriers, masonry
Ø Structural grade concrete

2.3 MERITS OF RECYCLED AGGREGATES

Ø It leads to conservation of natural resources, especially in regions where aggregates are scarce.
Ø New concrete made from recycled concrete aggregate generally has the same properties as stone or gravel aggregate.
Ø Use of any recycled material helps to keep that material out of landfills.
Ø Recycling practices also can decrease the environmental impact of obtaining / manufacturing the material from virgin resources.
Ø If recycling plants are centrally located and easily accessible, transport costs can also be substantially minimized.

2.4 LIMITATIONS OF RECYCLED AGGREGATES

The relative density decreases progressively as particle size decreases. The percentage reduction to compressive strength of recycled aggregate concrete as compared to original concrete is reported to range between 5%-32%. Concrete made with recycled coarse aggregates can obtain an adequate compressive strength. Generally the recycled aggregate has a higher absorption and a lower relative density than conventional aggregate concrete.

This results from the porous mortar and hardened cement paste adhered to the recycled aggregates. Absorption values typically range from 3% to 10%, depending on the concrete being recycled. The use of recycled fine aggregate can result in compressive strength reductions. The recycled aggregate concrete shows less workability because of its increased demand of water. These aggregates also show reduced tensile and flexuralstrengths. Also, the static modulus of recycled aggregate concrete is lower. However, drying shrinkage and creep of concrete made with recycled aggregates is up to 100% higher than concrete with a corresponding conventional aggregate. This is due to the large amount of old cement paste and mortar especially in the fine aggregate. Recycled concrete used as coarse aggregate in new concrete possesses some potential for alkali-silica-reaction if the old concrete contained alkali-reactive aggregate. The alkali content of the cement used in the old concrete has little effect on expansion due to alkali-silica-reaction

2.5 RECYCLING AND REUSE OF C & D WASTES IN CONCRETE

The recycling and reuse of construction & demolition wastes seems feasible solution in rehabilitation and new constructions after the natural disaster ordemolition of old structures. This becomes very important especially for those countries where national and local policies are stringent for disposal of construction and demolition wastes with guidance, penalties, levies, etc.

2.5.1 INTERNATIONAL STATUS

It has been estimated that approximately 180 million tones of construction & demolition waste are produced each year in European Union. In general, in EU,500 Kg of construction rubble and demolition waste correspond annually to each citizen. Indicatively 10% of used aggregates in UK are RCA, whereas 78,000 tons of RCA were used in Holland in

1994. The Netherland produces about 14million tons of buildings and demolition wastes per annum in which about 8 million tons are recycled mainly for unbound road base courses. The 285 million tons of construction waste produced in Germany per annum, out of which 77 million tons are demolition waste. Approximately 70% of it is recycled and reused in new construction work. It has been estimated that 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 approximately 2.7 billion tons of aggregate annually out of which 30-40% is used in road works and balance in structural concrete work. A recent report of Federal Highways Administration, USA refers to the relative experience from European data on the subject of concrete and asphalt pavement recycling. The rapid development in research on the use of RCA for the production of new concrete has also led to the production of concrete of high strength/performance.

In Catalonia (an autonomous community within Spain) the annual quantity of construction and demolition waste is approximately of 3.6 Million tons. An annual production is estimated at about 4 million tons per year for period 2001-06. In June 2001 the Catalonia government proposed a new recycling construction waste management scheme for 6 years, from 2001-06.

The objective is to increase from four recycling plants, to eleven in 2003 and eighteen in the year 2006, with a percentage of recycling estimated at 25% and 50% respectively. Following the II world war certain countries for example Germany was interested in the recycling of “dumping materials”. Germany takes as its aim in the reduction between 1995 and 2005 of half of its waste materials by recycling.

Seventy million tons of construction and demolition wastes are produced annually in the UK, and this is likely to increase considerably in the future. At present, approximately 10% of these wastes are recycled for use as aggregate, mainly as fill, drainage or sub-base material. The remaining 63 Mt of potentially useful material goes to landfill. The environmental and economic implications of this are no longer considered sustainable and, as a result, the construction industry is under increasing pressure to reduce this landfill.

According to the study commissioned by Technology information, forecasting and assessment council (TIFAC), 70% of the construction industry is not aware of recycling techniques.

2.5.2 INDIAN STATUS

There is severe shortage of infrastructural facilities like houses, hospitals, roads etc. in India and large quantities of construction materials for creating these facilities are needed. The planning Commission allocated approximately 50% of capital outlay for infrastructure development in successive 10th & 11th five year plans. Rapid infrastructural development such as highways, airports etc. and growing demand for housing has led to scarcity & rise in cost of construction materials. Most of waste materials produced by demolished structures disposed off by dumping them as land fill. Dumping of wastes on land is causing shortage of dumping place in urban areas. Therefore, it is necessary to start recycling and re-use of demolished concrete waste to save environment, cost and energy.

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%. Management of such high quantum of waste puts enormous pressure on solid waste management system.

In view of significant role of recycled construction material and technology in the development of urban infrastructure, TIFAC has conducted a techno-market survey on ‘Utilization of Waste from Construction Industry’ targeting housing and road segment. The total quantum of waste from construction industry is estimated to be 12 to 14.7 million tons per annum out of which 7-8 million tons are concrete and brick waste. According to findings of survey, 70% of the respondent have given the reason for not adopting recycling of waste from Construction Industry is “Not aware of the recycling techniques” while remaining 30% have indicated that they are not even aware of recycling possibilities. Further, the user agencies/ industries pointed out that presently, the BIS and other codal provisions do not provide the specifications for use of recycled product in the construction activities.

III. Literature Review

3.1 INTRODUCTION

In recent years certain countries have considered the reutilization of construction and demolition waste as a new construction material as being one of the main objectives with respect to sustainable construction activities. This thesis focuses on recycling of concrete waste as an aggregate in structural concrete. Many researchers have dedicated their work to describe the properties of these kinds of aggregates, the minimum requirements for their utilisation in concrete and the properties of concretes made with recycled aggregates. However, minor attention has been paid to durability aspect of Recycled Aggregate Concrete and to overcome its drawbacks. The main factors which influence the quantity of adhered mortar in recycled aggregate crushed (with the same machine and power) are as follows: a) water/cement ratio b) original concrete strength and c) Aggregate size. The grinding process has an influence on the amount of adhered mortar and the quality of recycled aggregates. a) Water/Cement ratio: The water/cem the amount of adhered mortar to crushed with the same grinding machine and employing the same power. The quantity of adhered mortar increases with the decrease of the size of the aggregate (with the same machine and same power) see figure

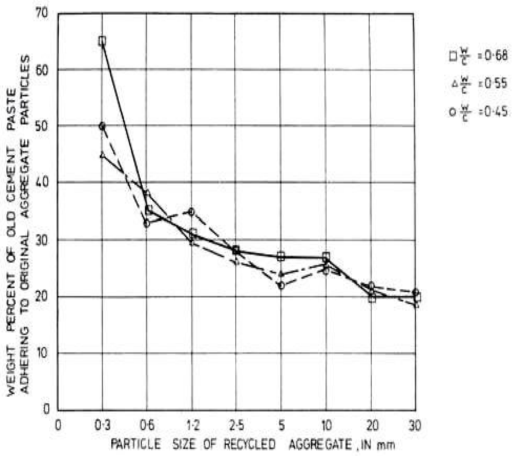

Fig 3.1 Weight percentage of c cement paste adhered to original aggregate recycled aggregate produced from original concretes made with different water

b) Strength of original concrete: The quantity of adhered mortar in the original aggregate is proportional to the strength of the original concrete (Hasaba, 1981), when the crushed concrete is ground with the same type of machine and the same energy is applied.

IV. Experimental Program

4.1 INTRODUCTION

Recycled aggregates are obtained from the waste crushed concretes. From quality point of view, the aggregates are heterogeneous in composition being derived from different materials and adhered mortar. The properties of recycled aggregates must be determined if the aggregates are to be used in concrete. The main aim of the present experimentation is to analyse the structural behavior of concrete made with different percentages of recycled aggregates, all of which were designed to have the same compressive strength. The strength and durability properties of the concrete produced by replacing conventional aggregates with recycled coarse aggregates in various percentages are evaluated. The objective of the experimental investigation is to assess the utility of recycled aggregate in the production of structural concrete.

Serious of test specimens comprising of cubes, cylinders and prisms of standard dimensions were cast for concrete mixes produced with different percentage replacement (0%, 25%, 50%, 75% and 100%) of conventional coarse aggregates with recycled concrete aggregates to study the strength and durability parameters. Similarly five concrete mixtures were produced with optimum dosage (900 g per m3) of Recron 3s synthetic fibres along with different percentages of recycled coarse aggregates (0%, 25%, 50%, 75% and 100%) for the study. The strength characteristics of concrete like compressive strength,tensile strength and flexural strength are established experimentally.

4.2 EXPERIMENTATION

The test program was planned in accordance to the objective of the experimentation. The grade of concrete adopted for all concrete mixes was M20 since it is the widely used structural concrete all over the world. All the concrete mixes are designed to have the same compressive strength. Recycled Aggregate Concrete (RAC) was produced by replacing the conventional aggregate by 0%, 25%, 50%, 75% and 100% with recycled coarse aggregate. Cubes, cylinders, prisms were casted to arrive at the strength parameters and durability parameters. The strength parameters were studied at the ages 3 days, 7 days, 28 days and 56 days. The durability parameters were studies for 30 cycles of chemical environment after 28 days of normal curing. Concrete mix with 0% recycled aggregates forms the basic reference mix to compare the results of mixes with different percentage of replacement of recycled aggregates.

4.3 MATERIALS

The various materials used in the experimentation namely cement, fine aggregate and coarse aggregate have been tested in the laboratory. The specifications and properties of these materials were presented in the subsequent sections. All the materials used in the study were tested in accordance to the Indian standards.

4.3.1 Cement

Cement used in experimental work was Ordinary Portland Cement of 43 grade from PRIYA brand. Cement used was fresh, of uniform colour, free from any lumps and foreign matter, and from the same batch. The properties of cement used were as in Table 4.1.

Table 4.1: Properties of Cement

S.No.	Property	Test values	Standard Values(IS 8112:1989)
1	Specific Gravity	3.11	3.125
2	Standard Consistency	28 %	28-32
3	Initial Setting Time (min)	215	>30
4	Final Setting Time (min)	360	<600
5	Fineness	4.75%	10

4.3.2 Coarse Aggregates

Conventional Coarse Aggregate from an established quarry was used. The coarse aggregates used were of size 20 mm and 10 mm. Demolished concrete from an old building at Diamond Park, Visakhapatnam was the source for recycled coarse aggregate. The grade of source concrete was M15 and was with coarse aggregate of basalt origin with 20mm down size. Demolished concrete was transported to Strength of Materials lab of Civil Engineering Department where it was broken manually. Broken aggregates were sieved through standard sieves to obtain the aggregates of 20 mm and 10 mm size. Utmost care has been taken to minimize the adhered mortar to the aggregates. No specimens from testing laboratory of S.M lab were used as concrete made with aggregates obtained from such specimens yield aggregates with high content of adhered mortar. The percentage usage of coarse aggregates in the production of concrete was 60%, 40% for 20 mm and 10 mm respectively. The coarse aggregates (both conventional and Recycled) were tested in accordance to IS-383 1970. The properties and test results of coarse conventional and recycled aggregates used were shown in the Table 4.1, Table 4.4.and Table 4.6

TABLE 4.1 Material Properties of Coarse Aggregates

S.No.	Property	Conventional Aggregate	Recycled aggregate
1	Max. nominal size (mm)	20.00	20.00
2	Specific Gravity	2.81	2.7
3	Bulk Density (loose) in kg/m3	1510	1480
4	Bulk Density (Rodded) in kg/m3	1680	1640
5	Fineness Modulus	70867	7.69
6	Impact Value	18.30%	21.10%
7	Crushing Value	21.10%	22.20%
8	Water Absorption	0.50%	2.50%

4.3.3 Fine Aggregate

River sand conforming to Zone-II as per IS 383:1970 was used. The fine aggregate was clean, inert and free from organic matter, silt & clay. The Fine aggregate as dried before use. The properties of fine aggregate were presented in the Table 4.2

TABLE 4.2 Properties of Fine Aggregate

S.No.	Property	Test value
1.	Specific Gravity	2.60
2.	Bulk Density (kg/m^3)	1648
3.	Fineness Modulus	2.605
4.	Water Absorption	0.50%

4.3.4 Water

Portable water from laboratory taps was used for concrete production. Water from same source was used for curing.

4.3.5 Fibre

Fibres used in the present investigation were Reliance Industries Limited make with brand name Recron 3S. The properties of fibre are presented in Table 4.3

Table 4.3 Properties of Recron 3S fibre

S.No.	Property	Test value
1.	Material	Synthetic Fibre – Polyester
2.	Cross Section	Triangular
3.	Fibre length	12 mm
4.	Specific Gravity	1.34
5.	Colour	Brilliant White
6.	Melting Point	240°C

TABLE 4.4 Grading of Conventional Coarse Aggregates

	Percentage passing for aggregate nominal size						Experimental results
	63 mm	40 mm	20 mm	16 mm	12.5 mm	10 mm	
80 mm	100	-	-	-	-	-	-
	85-100	100	-	-	-	-	-
40 mm	0-30	85-100	100	-	-	-	100
20 mm	0-5	0-20	85-100	100	-	-	93
16 mm	-	-	-	85-100	100	-	-
12.5 mm	-	-	-	-	85-100	100	-
10 mm	-	0-5	0-20	0-30	0-45	85-100	16.17
4.75 mm	-	-	0-5	0-5	0-10	0-20	-
2.36mm	-	-	-	-	-	0-5	-

TABLE 4.5 Grading of Recycled Coarse Aggregates

IS sieve designation	Percentage passing for aggregate nominal size						Experimental results
	63 mm	40 mm	20 mm	16 mm	12.5 mm	10 mm	
80 mm	100	-	-	-	-	-	-
63 mm	85-100	100	-	-	-	-	-
	0-30	85-100	100	-	-	-	100
20 mm	0-5	0-20	85-100	100	-	-	88
16 mm	-	-	-	85-100	100	-	-
12.5 mm	-	-	-	-	85-100	100	-
10 mm	-	0-5	0-20	0-30	0-45	85-100	6.4
4.75 mm	-	-	0-5	0-5	0-10	0-20	-
2.36mm	-	-	-	-	-	0-5	-

TABLE 4.6 Grading of Conventional Fine Aggregates

I.S. Sieve designation	Percentage passing by weight for				Experimental results
	Grading Zone I	Grading Zone II	Grading Zone III	Grading zone IV	
10 mm	100	100	100	100	100
4.15 mm	90-100	90-100	90-100	95-100	99
2.36 mm	60-95	75-100	85-100	95-100	94
1.18 mm	30-70	55-90	75-100	90-100	64
600 micron	15-34	35-59	60-79	80-100	26
300 micron	5-20	8-30	12-40	15-50	8
150 micron	0-10	0-10	0-10	0-15	1

4.3.6 Chemical Admixture

With same water-cement ratio for both conventional aggregate concrete and recycled aggregate concrete, loss of workability was observed due to higher water absorption of water for recycled aggregates. In order to obtain medium workability as that of conventional aggregate concrete, CONPLAST SP 430 A2 super plasticizer from FOSROC Chemicals was used as water reducing agent to achieve required workability. Conplast SP 430 A2 is based on sulphonated Naphthalene polymers and is a brown liquid instantly dispersible in water. Theproperties of CONPLAST SP 430 A2 are shown in Table 4.8

TABLE Properties of CONPLAST SP 430 A2

S.No.	Property	Value
1	Specific Gravity	1.20 to 1.21 at 30^{0}C
2	Chloride	Nil
3	Air entrainment	1 % (additional)

V. Test Results and Analysis

5.1 GENERAL

To examine the effect of replacement of conventional coarse aggregates with recycled coarse aggregates, four different concrete mixtures using different percentages of recycled coarse aggregates (25%, 50%, 75% and 100%) with the same compressive strength were produced. All the concrete mixtures with different percentage of replacement were compared with the reference concrete mix produced with conventional coarse aggregates i.e. 0% replacement. Similarly five concrete mixtures were produced with optimum dosage of Recron 3S synthetic fibres (900 g per m3) along with different percentages of recycled coarse aggregates (0%, 25%, 50%, 75% and 100%) with the same compressive strength.

Series of tests comprising compressive strength test, split tensile strength test and flexural test were performed on the concrete specimens to obtain the strength characteristics of concrete made with recycled coarse aggregates and conventional aggregates. Similarly series of tests were carried out on concrete mixes with Recron 3S synthetic fibres along with recycled coarse aggregates and conventional aggregates. For durability assessment of all the concrete mixes, compressive strength test and weight loss test were performed. This investigation presents an experimental study to demonstrate that demolished waste can be successfully used as recycled aggregates in concrete with adequate measures for proper mix design and field control.

5.2 STRENGTH CHARACTERISTICS

Assessment of the mechanical properties of recycled aggregate concrete and conventional aggregate concrete was made through series of destructive test like compressive strength test, split tensile strength test and flexural strength test. Nondestructive tests such as Rebound hammer test and Ultrasonic Pulse Velocity test were performed on test specimens to arrive at the strength characteristics of concretes produced with recycled coarse aggregates and conventional aggregates. Similarly the above tests were conducted on test specimens of concrete mixes fibres along with recycled coarse aggregates and conventional aggregates.

5.2.1 Compressive Strength

The compressive strength test was conducted on cube test specimens for concrete mixes made with conventional aggregates and recycled coarse aggregates (for every percentage of replacement). The test was conducted on test specimens at the ages of 3, 7, 28 and 56 days after proper curing till the day of test. Similarly compressive strength test was carried out on concrete mixes with Recron 3S fibres along with conventional aggregates and recycled coarse aggregates.

The compressive strength values obtained from the test for Conventional Aggregate Concrete (CAC), Concrete with different percentage (25, 50, 75 and 100) of Recycled Aggregate and concrete with fibres along with conventional aggregates. The results were plotted in figures 5.1to 5.3

Comparison of 28 Days Compressive strength of RAC Mixes with CAC

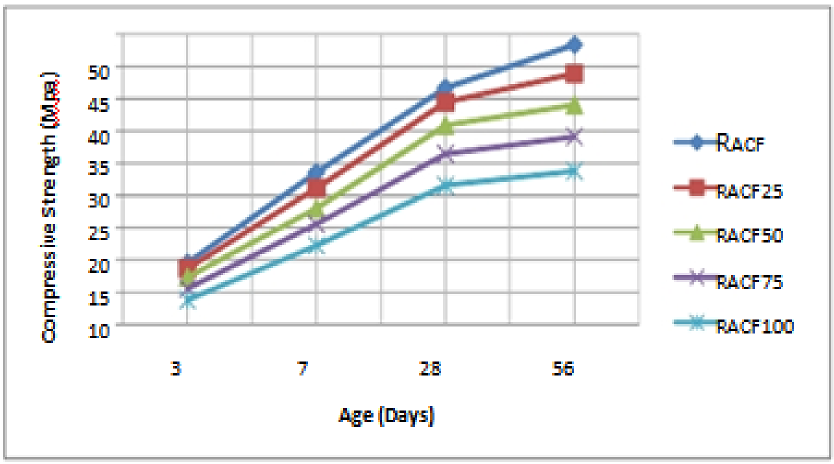

Fig 5.1 Variation of Compressive strength of CACF and RACF mixes with age

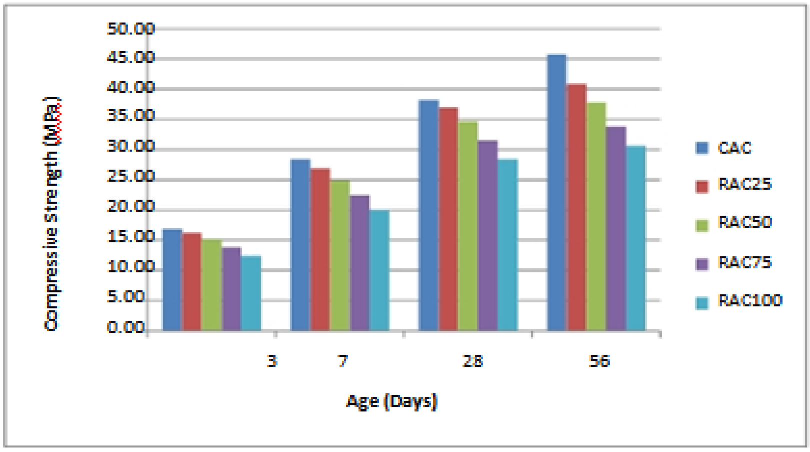

Fig 5.2 Variation of Compressive strength of CAC and RAC mixes with age

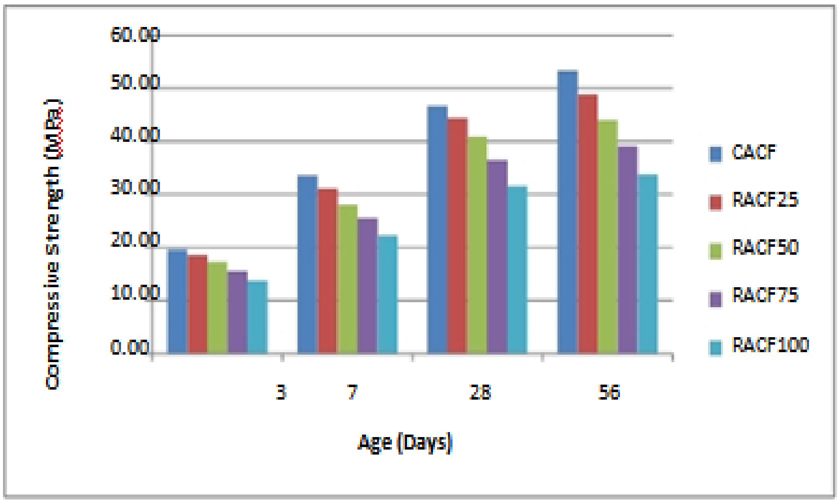

Fig 5.3 Variation of Compressive strength of CACF and RACF mixes with age

VI. Conclusions

Recycling and reuse of building wastes have been found to be an appropriate solution to the problems of dumping hundreds of thousands tons of debris accompanied with shortage of natural aggregates. The use of recycled aggregates in concrete proves to be a valuable building material in technical, environment and economical respect. In accordance with the experimental phase carried out in this study, the following conclusions are drawn:

1. The specific gravity and bulk density of recycled coarse aggregate is found to be less than conventional coarse aggregates.
2. The water absorption is relatively higher for recycled aggregates. The recycled aggregates had 2.5% water absorption.
3. All the mixes attained the target mean strength. Cube Strength of RAC is about 36.89 MPa to 28.44 MPa with the replacement percentage in the range of 25 to 100.
4. Concrete made with 100% replacement of conventional coarse aggregates with recycled coarse aggregate had 26 % less compressive strength than conventional concrete at 28 days with same w/c ratio (0.55) and quantity of cement (330 kg/m3).
5. Concrete made with 25% replacement of conventional coarse aggregate with recycled coarse aggregates achieved the same mechanical properties as that of conventional concrete employing same w/c ratio (0.55) and quantity of cement (330 kg/m3).
6. Concrete made with 50% and 75% replacement of conventional coarse aggregate with recycled coarse aggregates achieved the compressive strength of 35 MPa and 32 MPa respectively at 28 days.
7. Concrete made with 50% and 75% replacement of CCA with RCA had the strength loss of 9% and 17% respectively at 28 days when compared to conventional aggregate concrete.
8. On addition of fibres to RAC, the increase of compressive strength of RAC with 100% replacement is 11% for 28 days and 10% for 56 days. The increase of compressive strength for 50% and 25% replacement is 18% and 20% respectively for 28 days, which is at par with conventional concrete whose increase in compressive strength is 22%.
9. The decrease of tensile strength for 100% replacement of CCA with RCA is 28% for 28 days and 29% for 56 days. Concrete with 50% recycled coarse aggregates had a decrease of 18% and 19% in tensile strength for 28 days and 56 days respectively.
10. On addition of fibres to RAC, the increase of tensile strength of RAC with 100% replacement is 19% for 28 days and 16% for 56 days. The increase of tensile strength for 50% and 25% replacement is 24% and 27% respectively for 28 days, which is at par with conventional concrete whose increase in tensile strength is 27%.
11. The decrease of flexural strength for 100% replacement of CCA with RCA is 21% for 28 days and 22% for 56 days. Concrete with 50% recycled coarse aggregates had a decrease of 11% and 13% in flexural strength for 28 days and 56 days respectively.
12. On addition of fibres to RAC, the increase of flexural strength of RAC with 100% replacement is 10% for 28 days and 8% for 56 days. The increase of flexural strength for 50% and 25% replacement is 15% and 19% respectively for 28 days, which is at par with conventional concrete whose increase in flexural strength is 20%.
13. Compressive strength, Tensile strength and Flexural strength results of RAC show decrease in strength with increase in percentage replacement of conventional aggregates by recycled aggregates, this is in agreement with the results obtained by other researchers. However, RAC with fibres showed improvement in mechanical properties when compared to RAC.

14. On addition of fibres the compressive strength of conventional concrete is increased by 22%, the tensile strength is increased by 27% and the flexural strength is increased by 20% when compared to conventional concrete without fibres.
15. The loss of compressive strength due to marine attack is about 1% with maximum of 1.4% for mix with 100% replacement. The weight loss due to marine attack is about 0.4 % with maximum of 0.6% for mix with 100% replacement.
16. The loss of compressive strength due to sulphate attack is about 1.4% with maximum of 1.76% for mix with 100% replacement. The weight loss due to sulphate attack is about 1.2 % with maximum of 1.6% for mix with 100% replacement.
17. The loss of compressive strength due to acid attack is about 2% with maximum of 3.5% for mix with 100% replacement. The weight loss due to acid attack is about 2% with maximum of 2.6% for mix with 100% replacement.
18. Assessment of the quality of concrete in terms of mass loss and compressive strength loss revealed that quality of concrete is good under marine, sulphate and acid attack. There has been not much reduction in strength and mass under the above said attacks.
19. NDT results revealed that the strength of conventional and recycled aggregate concrete is more or less equivalent to destructive tests and quality of concrete in terms of homogeneity is good.
20. The test results obtained from non-destructive testing are in accordance with the conventional test results.
21. Concrete made with recycled aggregates need more super plasticizer to achieve the same workability as that of conventional concrete. The observations made during the present investigation are in agreement with the results reported by earlier investigators. The experimental study has helped to investigate the various properties of RAC as global replacement of conventional aggregates with recycled aggregate in the production of Structural concrete. In view of the other advantages such as conservation of natural resources, free the recycled material from landfills and elimination of disposal problems, the Recycle aggregates and Recycled Aggregate Concrete can be considered as a potential and suitable alternative material with a bright future.

Recommendations for Further Studies

1) The study on recycled aggregate concrete can be further extended to investigate the behavior of recycled aggregate concrete with Pozzolanic or Mineral admixtures like fly ash, Silica fume, Metakaoline etc.
2) Study can be carried out on high strength concrete made with recycled aggregates.
3) The failure mechanisms of concrete made with recycled aggregates can be investigated.
4) Microscopic analysis can be carried out on the interfacial transition zone of recycled aggregate concrete.

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