Cost Optimization & Performance Assessment of Concrete with Partial Replacement of Natural Aggregates by Recycled Coarse Aggregates

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Abstract— Recycled concrete aggregate (RCA) is a construction material, which is being used in the Indian construction industry more frequently than it was in the past. The environmental benefits associated with RCA use, such as reduced land filling and natural aggregate (NA) quarrying, have been identified by industry and government agencies. This has resulted in some incentives to use RCA in construction applications. Some properties of RCA are variable and as a result the material is often used as a structural fill, which is a low risk application. The use of RCA in this application is beneficial from an overall sustainability perspective but may not represent the most efficient use of the material. Efficient use of a material means getting the most benefit possible out of that material in a given application. The initial step in efficient material use is evaluating how a material affects its potential applications. In the case of RCA, this includes its use in concrete as a coarse aggregate. In this study, Recycled concrete aggregates are used in concrete in replacement of nominal concrete aggregates, replacement of various percentages like 15 & 25% have been done. After the duration of 3,7, 14 & 28 days cubes have been tested. This study also enhance the performance of the fresh and hardened properties of a proposed green concrete mixed using construction and demolition waste as a recycled aggregate curing with fresh water. Fresh and hardened properties of the concretes, including workability, strength gain, drying shrinkage, permeability, and microstructure, were characterized and studied. The study reveals that the use of RCA has substantial effects on concrete performance. These strategies, however, somewhat reduce the green aspect of the proposed seawater-mixed concrete with RCA.

Keywords: Concrete, Recycled Coarse Aggregate, Construction & Demolition Waste, Compressive Strength, Tensile Strength, Flexural Strength, Workability

I. Introduction

Concrete is the most widely used man made construction material in the world. Concrete is a composite material that consists essentially of a binding medium within which are embedded particles or fragments of aggregate. In hydraulic-cement concrete, the binder is formed from a mixture of hydraulic cement and water (Mehta & Montario). Concrete in the broadest sense, is any product or mass made by the use of a cementing medium. Generally, this medium is the product of reaction between hydraulic cement and water. But, these days, even such a definition would cover a wide range of products; concrete is made with several types of cement and also contains pozzolana, fly ash, blast-furnace slag, micro silica, additives, recycled concrete aggregate, admixtures, polymers, fibres, and so on, and these concretes can be heated, steam-cured, autoclaved, vacuum-treated, hydraulically pressured, shock-vibrated, extruded, and sprayed. The mixture when placed hardens into rock like mass known as concrete. The hardening is the result of the chemical reaction between cement and water which continues along with time; as a result concrete hardens with ages. The matrix of concrete is very simple; the larger aggregates called as coarse aggregate (size range between 40mm to 4.75mm) have voids which are filled by sand or fine aggregate (size range between 4.75mm to 75µ). The voids of fine aggregates are filled by cement and water paste. In addition to filling the voids, the cement water paste also coats the surfaces of fine and coarse aggregates and binds them together in the compacted solid mass.

India is a developing country and the need of infrastructure demand is increasing at a larger extent. This demand to be fulfilled requires a large quantity of resources as aggregate, sand, cement etc. As these materials which were at abundance at some time, are going to be finished in near future due to increase in the intervention of mankind.

At the same time, scope exists for the development of new or improved technologies for construction using alternate materials. The mineral aggregates, associated binders and modifiers used in the industry at present, occur in sufficient quantities to satisfy the current demands.

Alternative materials are unlikely to be found in sufficient quantities for building construction to replace existing materials and the objective of these new or improved technologies should therefore, be focused on utilizing the currently available materials in a more efficient and cost-effective manner. In addition, consideration of the environment through sustainable development of buildings is of paramount importance. This is applicable to both new construction and rehabilitation works, with the latter placing emphasis on recycling as focal point in future technologies.

II. Objective

The following are the objectives of the research work:
- To study about the properties of recyclable aggregates.
- To save natural aggregates for future needs.

III. Materials Used

A. Cement

Ordinary Portland Cement (OPC) of 43 grade is taken for this project, as per IS: 8112-1989.

S.NO.	Properties	Value
1	Specific Gravity	3.16
2	Standard Consistency	29%
3	Initial Setting Time	37 min
4	Final Setting Time	408 min
5	Compressive Strength	44.16

Table 1: Properties of Cement

B. Sand

The sand taken for this project was tested for water absorption, specific gravity, bulk density and particle size grading as per IS: 2386 (I & III). Sand in each test was taken after sampling it as per IS: 2430-1969.

S.NO.	Properties	Value
1	Water Absorption	1.21%
2	Specific Gravity	2.63
3	Apparent Specific Gravity	2.64
4	Bulk Density	1.512
5	Fineness Modulus	2.14

Table 2: Properties of Sand

C. Coarse Aggregates

The available coarse aggregate is of two types: a) on basis of size as 20mm and 10mm, b) on basis of source as natural and C & D waste. These two aggregates are tested to know various physical properties such as size, toughness, hardness etc. These aggregates were tested as per Indian Specifications to ensure the quality of the aggregate. The test performed are water absorption (as per IS: 2386 part III-1963), specific gravity (as per IS: 2386 part IV-1963), flakiness and elongation value test, impact test (as per IS: 2386 part IV-1963), crushing value (as per IS: 2386 part IV-1963) and Los Angles abrasion value (as per IS: 2386 part IV-1963).

S.No.	Properties	NA	RCA
1	Water Absorption	0.27	3.05
2	Specific Gravity	2.75	2.66
3	Bulk Density (loose)	1498	1487
4	Bulk Density (Compacted)	1711	1708
5	Fineness Modulus	7.04	7.06
6	Impact Value	17.3	36.78
7	Crushing Value	22.06	21.11

Table 3: Properties of Coarse Aggregates

D. Water

Water used in concrete mix is potable water conforming the specification of IS 456:2000. Water used for mixing is free from injurious amount of oils, acids, alkalis, salts, sugar, organic materials or other substances that may be deleterious to concrete.

IV. DESIGN MIX

The grade of concrete depends upon the characteristic compressive strength of the concrete which depends on the factor of mix design. In this study, three different grades of concrete used for the comparative purpose whose nominal design mix have been tabulated below as per Indian Standards. For the purpose of comparison, three nos. of samples have been made of each nominal design mix grade of concrete with the given water cement ratio as per IS 10262.

S. No.	Grade of Concrete	Nominal Mix	W/C ratio
1	M 20	1:1.5:3	0.54
2	M 25	1:1:2	0.51
3	M 30	1:0.75:1.5	0.48

Table 4: Ingredients of Concrete per cubic meter

V. EXPERIMENTAL STUDY & RESULTS

This includes testing of different materials of concrete individually for checking its suitability for the mix. The properties of mix fairly depends on the property of material; so to get proper mix of expected strength, the material of mix should also be as per standards. Testing of concrete viz. various strength and durability criteria and their significance are discussed further.

A. Compressive Strength Test Results

Compressive strength is the most common and widely used test in concrete to measure its strength. For concrete, the cube specimens of 150*150*150 mm size are prepared. Maximum size of aggregates is restricted to 20mm. The general practice is to test the sample at 7 days and 28 days when concrete develops approximately 75% and 100% strength respectively. Ages of 13 weeks and one year are recommended if tests at greater ages are required. The concrete was tested immediately after removing it from water, wiping the surface and carefully removing any dirt, sand or other such material to have smooth even surface and rest of the specification are followed as per IS:516-1959. The strength is calculated as follows:

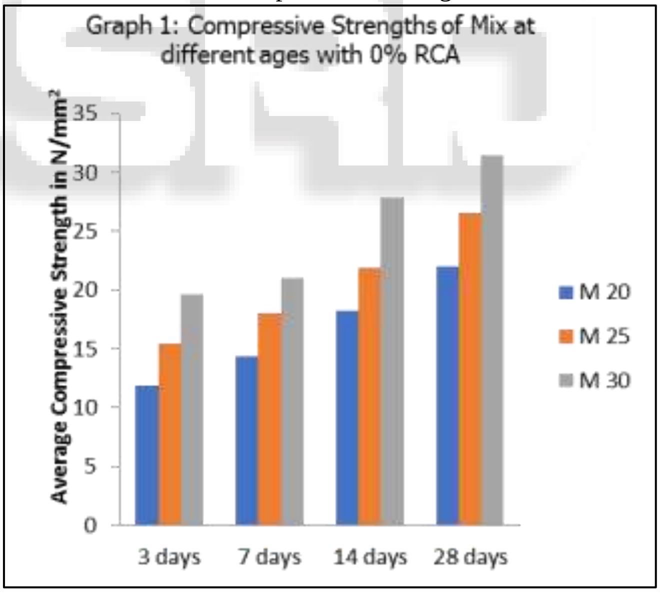
$f_c = P_c/A_c$

Where,

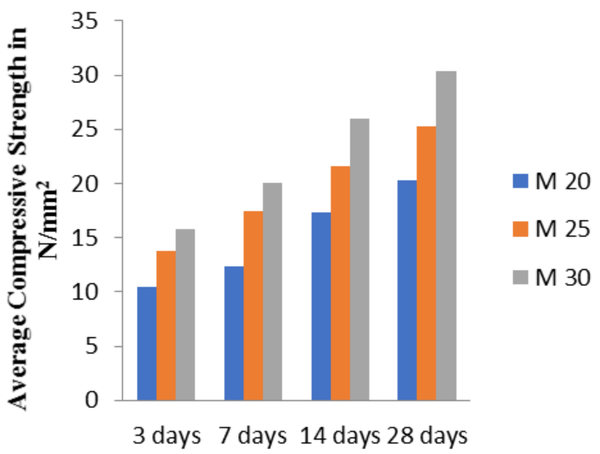
f_c= Compressive Strength of concrete

P_c = Load Sustained by cube in tonnes

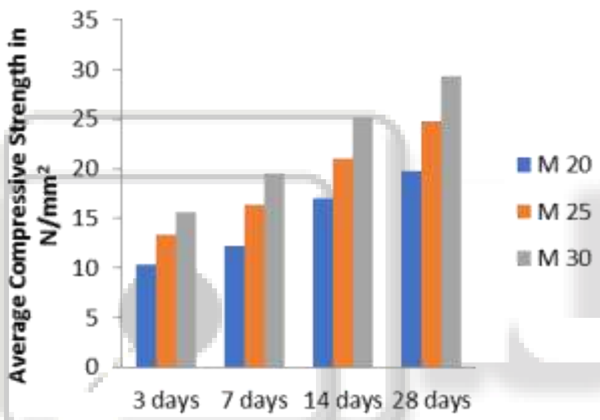
A_c = Area of Concrete Exposed to loading



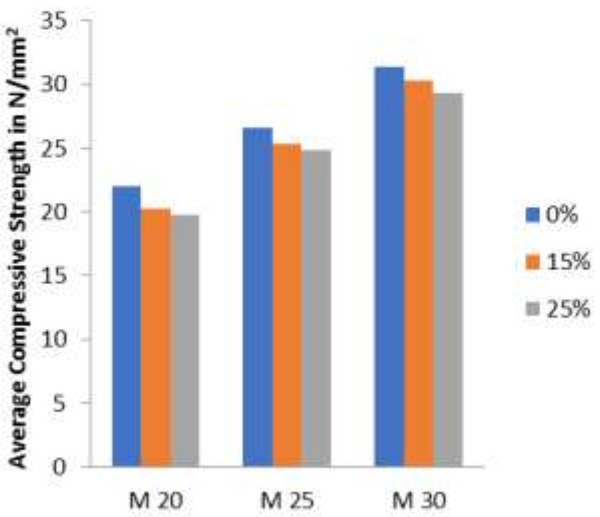
Graph 2: Compressive Strengths of Mix at different ages with 15% RCA



Graph 3: Compressive Strengths of Mix at different ages with 25% RCA



Graph 4: Comparison of Compressive Strengths at 28 days of different grades of concrete with 0%, 15% & 25% RCA



B. Tensile Strength Test Results

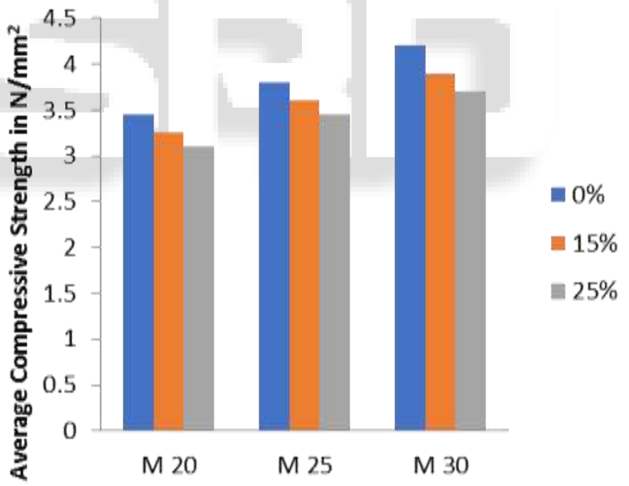
Concrete is known for its compressive strength and weak tensile strength but it's important to know the tensile strength as tensile stress are likely to develop in concrete due to drying shrinkage, rusting of reinforcement, temperature gradient and many such reasons, so it's important to have knowledge of tensile strength of concrete. In case of concrete slab the tensile stress are developed by two principle sources, load and volume change in concrete. Loads may cause high tensile stresses due to bending when inadequate support is there. Volume changes are due to changes in moisture and temperature generally called as warping stress.

Due to difficulty in applying uniaxial tension to a concrete specimen, the tensile strength of the concrete is determined by indirect test methods:
Split Cylinder Test (2) Flexure Test.

C. Flexure Strength Test Results

For this beams are prepared of 500 mm length and 100*100 mm cross section is used. Test immediately on removal from the water while they are still in a wet condition. Concrete is wiped to remove loose material from its surface and placed in machine such that the upper face during casting is on the upper side.

Graph 5: Flexural Strength at 28 days with 0%, 15% & 25% RCA



D. Split Cylinder Test Results

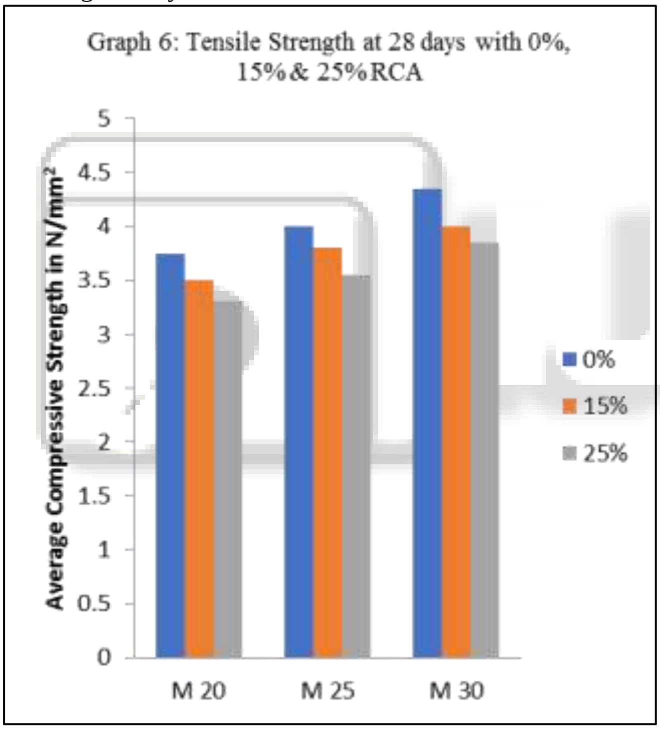
It is the standard test, to determine the tensile strength of concrete in an indirect way. This test could be performed in accordance with IS: 5816-1970.

A standard test cylinder of concrete specimen (300 mm X 150mm diameter) is placed horizontally between the loading surfaces of Compression Testing Machine (Fig-4). The compression load is applied diametrically and uniformly along the length of cylinder until the failure of the cylinder along the vertical diameter. To allow the uniform distribution of this applied load and to reduce the magnitude of the high compressive stresses near the points of application of this load, strips of plywood are placed between the specimen and loading platens of the testing machine. Concrete cylinders split into two halves along this vertical plane due to indirect tensile stress generated by poisson's effect.

Due to this compressive loading, an element lying along the vertical diameter of the cylinder is subjected to a vertical compressive stress and a horizontal stress (Fig-4). The loading condition produces a high compressive stress immediately below the loading points. But the larger portion of cylinder, corresponding to its depth is subjected to uniform tensile stress acting horizontally. It is estimated that the compressive stress is acting for about 1/6 depth and the remaining 5/6 depth is subjected to tension due to poisson's effect. Assuming concrete specimen behaves as an elastic body, a uniform lateral tensile stress of f_t acting along the vertical plane causes the failure of the specimen, which can be calculated from the formula as,

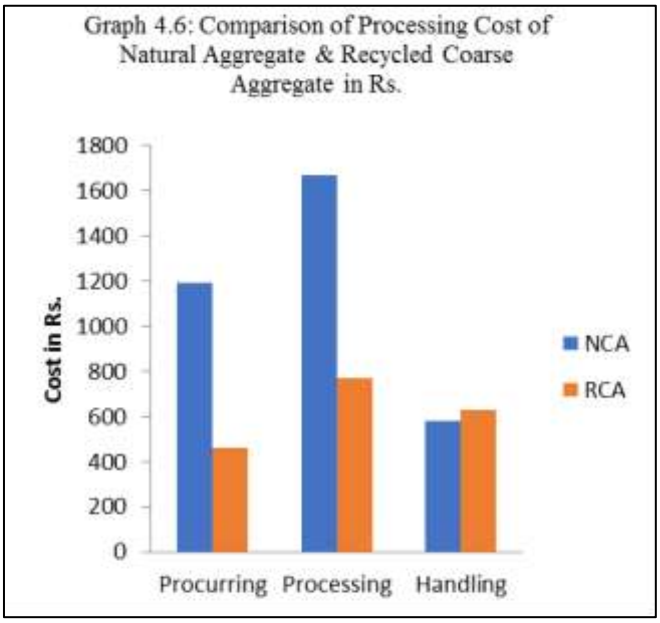
$$f_t = 2P/\pi DL$$

where,
f_t = Lateral Tensile Stress,
P= Compressive Load at failure
D= Diameter of Cylinder
L= Length of Cylinder



E. Cost Analysis Results

The following costs are collected from crusher plants by site survey. The total processing cost of natural and recycled aggregate are compared and tabulated below.



Cost Effectiveness = [(3440.00-1860.00)/3440.00] * 100
Cost Effectiveness = 46%

VI. Conclusions

Based on the study, the following conclusions are drawn:

1) Compressive strength of concrete in 28 days was found to be 1% to 1.5 % more than that of characteristic strength of concrete in 28 days for the given grade for the 15% use of recycled aggregates in the mix while flexural strength and tensile strength for 28 days for the replacement of natural aggregates by recycled coarse aggregates up to 15% are 5 to 8 % less than the strength determined by the use of natural aggregates which is satisfactory. Hence use of recycled aggregate up to 15% does not affect the functional requirements of the structure as per the findings of the test results.
2) Compressive strength for 25% use of RCA was found to be 2% to 8% less than the characteristic strength of given grade in 28 days while its flexural and tensile strength is also 10% to 15% less than the actual strength. Hence use of RCA up to 25% may be not significant for the high grade of concrete.
3) Physical properties of the C & D waste aggregates in combination with the natural aggregates show the suitability of these aggregates for construction and maintenance purposes. Various tests conducted on recycled aggregates and results compared with natural aggregates are satisfactory as per IS 2386.
4) As a result of Cost Analysis, the RAC is 46% cost-effective when compared with the NAC.
5) Due to use of recycled aggregate in construction, energy & cost of transportation of natural resources & excavation is significantly saved. This in turn directly reduces the impact of waste material on environment.
6) The above test results are obtained without using any admixtures. And the design mix is based on the nominal mix ratio given in IS 456 2000.

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