STUDY OF MECHANICAL PROPERTIES OF CONCRETE WITH FINE AND COARSE RECYCLED AGGREGATES

A Synopsis submitted to Gujarat Technological University

In

Civil Engineering

by

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Synopsis

STUDY OF MECHANICAL PROPERTIES OF CONCRETE WITH FINE AND COARSE RECYCLED AGGREGATES

1. Abstract

Depletion of natural resources for preparing concrete is a major issue, on the other hand utilization of Construction and demolition (C&D) waste get dumped without disposal. Recycling and reuse of these C&D wastes like recycle coarse aggregate and recycle fine aggregate may reduce the usage of natural resources and it can also address the issue of environment sustainability. However use of these materials in construction industry in the making of concrete is highly challenging. Significant research efforts are required to study the engineering properties of concrete incorporating such recycled material. The quality of recycled aggregate is greatly affected by cement mortar attached to the surface of aggregate. This attached mortar results in higher porosity; higher water absorption rates, reducing the strength and mechanical performance of concrete made from such recycled aggregate. Present research aims to study the properties of concrete incorporating wastes from demolished concrete after applying different methods of treatment. The treatment processes under study are (1) Abrasion treatment (AT) (2) Cement slurry treatment (CST) (3) Chemical treatment (CT).

The aim of study is to provide base for the use of Recycled Aggregate (RA) in structural concrete by conducting Experiments to get mechanical properties of concrete produced with treated coarse RA and fine recycled aggregate compared to concrete with natural coarse and fine aggregates. Initially, physical and mechanical properties of natural materials and RA are studied and compared. A mix proportion for M20 grade was then calculated to produce 19 series of concrete mixture for all three types of treated coarse aggregates. RAC produced with different percentage of coarse and fine recycled aggregate are tested.

The Properties of RAC were studied and influence of RA on slump value of fresh concrete was analyzed. The results confirmed that among all the three treatments, abrasion treatment (AT) is more effective and efficient. RAC (AT) gives higher compressive strength compared to other kind of RAC. Furthermore, to study the effectiveness of this treated RA (AT)
hardened properties of RAC were also investigated for higher grade of concrete like M40, M50, M70 with different percentage of coarse and fine recycled aggregates.

The results show that partial replacement of 30% coarse RA and 50% fine RA produced at par compressive strength to NAC. In order to study the stress strain behaviour of RAC, modulus of elasticity was experimentally compared with IS code provision and found acceptable.

2. Brief Description on the State of Art of Research Topic

Literature review for the present study is carried out broadly in the direction of concrete made of recycled materials for sustainability. The Conclusions arrived from various authors, will be briefly presented. Gonçalves and Neves state that the best size distribution and shape are obtained when the materials are crushed using a jaw crusher and then a rotary crusher (primary and secondary crushing), because part of the weaker mortar adhering to the original aggregates is lost in the process [2] Etxeberria focused on the study of concrete with different percentages of RA and studied their macroscopic and microscopic structure to observe the effect on durability. The author says that the density of recycled concrete aggregates is proportional to both the source concrete’s strength and particle size [3]. The most distinguished feature of RA is its old adhered mortar which makes it porous due to high mortar content, inhomogeneous and less dense [4]. Some researchers have reported in their studies that around 20% of cement paste is found attached to the surface of RA for particle size range from 20 to 30mm [5]. Other researcher like Poon et al. reported that RA extracted from crushing of waste concrete consists of 65–70% natural coarse and fine aggregate and 35–30% of cement paste by volume.[6] There is always a reciprocal relationship between this adhered mortar and the quality of RA.

Properties of fresh concrete such as workability and wet density are greatly affected by a number of factors such as w/c ratio; the characteristics of the constituent materials of concrete, especially the aggregate i.e. type of aggregate, maximum size of aggregate, water absorption of aggregate etc. Workability of concrete also gets affected by other physical parameters of aggregate such as surface texture, aggregate size, and shape of aggregate. In case of Recycled Aggregate Concrete (RAC), the slump loss is more than Natural Aggregate Concrete (NAC) and it is difficult to meet the required workability [7] Being porous in nature, it requires more water than conventional concrete to obtain the same workability. Tabsh and Abdelfatah [8] in their study concluded that RAC demands 10% extra water to achieve the same slump when RA is
used instead of natural aggregate. Even if keeping w/c ratio constant; aggregate type and the quantity of Recycled Concrete Aggregate (RCA) can also affect the slump of RAC mixes [9]. Compressive strength of Recycled aggregate concrete largely depends on many parameters like replacement level of RA, w/c ratio, moisture condition of RA etc [10]. It also depends on the physical and the mechanical properties of RA such as the crushing strength of aggregates. It has been observed from experimental investigations that the compressive strength of RAC is greatly influenced by the increment in the replacement percentage (%) of RA using the same w/c ratio [11]. The reduction in compressive strength is up to 30% as compared to natural aggregate concrete at 100% replacement [12,13].

The other mechanical property of RAC is the split tensile strength and flexural strength which represents similar behaviour as compressive strength with the increase in RA quantity. Several past investigations on RAC showed that the effect of RA content on split tensile strength is less than that on compressive strength. Few other authors [14, 15] in their study have mentioned that the decrease in split tensile strength is up to 10% with respect to different RA replacement percentage. However, Rao et al. [16] from their study investigated that the reduction in split tensile strength is up to 24% at 100% replacement by RA. Normally, it has been found that the split tensile strength and flexural strength of RAC mainly depend on the quality and surface characteristics of RA regardless the replacement level of RA [17]. Z. Chen et al in his study concluded that Flexural strength to cube compressive strength ratio of different aggregate replacement percentage recycled concrete is 0.12. [18]

R. Purushothaman et al. [19] in their studies concluded that the compressive strength and static modulus of elasticity of recycled aggregate concrete are lower than natural aggregate concrete. However, the compressive strength and static modulus of elasticity of recycled aggregate concretes prepared with recycled aggregate obtained from sulphuric acid treatment is as good as natural aggregate concretes. M. Behera et al. [20] reveal that the use of RA is from C&D waste is contributing towards a sustainable development in construction industry.
3.1 Objectives of work

- To investigate the influence of treatment methods on properties of recycled aggregate.
- To determine fresh and hardened properties of different grades of concrete incorporating various percentage of treated recycled coarse aggregate and recycled fine aggregate content;
- To determine the optimum % replacement of natural sand and Natural aggregate with recycled fine aggregate and coarse aggregate.
- To verify the stress strain behaviour of recycled aggregate concrete.

3.2 Scope of work

Stage-I

(1) Preliminary investigation carried out to determine the physical and mechanical properties of natural and recycled material.
(2) Application of Different Treatments to coarse Recycled Aggregate, in this study there were three types of treatment under consideration namely (1) Abrasion treatment, (2) Cement slurry treatment (3) Chemical treatment.
(3) Determination of physical and mechanical properties of coarse RA after treatment.

Stage -II

(1) Detailed Experiments programme to study fresh and hardened properties of M20 grade of concrete prepared with - 10,30,50,100 % replacement of natural sand with Fine RA and 10,20,30 % replacement of natural coarse aggregate with coarse recycled aggregates.
(2) In this stage of study for each type treatment there are 19 mixes with percentage replacement of coarse and fine RA as mention above.

Stage-III

(1) It is required to find out the best effective technique among all for coarse RA, based on the analysis of the result of stage II experiments.
(2) With this effective treatment of aggregate, further study on fresh and hardened properties of RAC for grade M40 and M50.
Stage-IV

(1) Experiments carried out to determine the strength of high strength concrete containing coarse RA and Fine RA and compare with NAC.

Stage-V

(1) Experiments to verify the stress strain behaviour recycled aggregate concrete

4. Significance of Research

1) Increase the use of recycled coarse aggregate and recycled fine aggregate in same concrete mix.

2) Conservation of natural resources hence reduction in the use of natural coarse aggregate and fine aggregate for concrete work

3) Overcome the performance issues, less workability, low strength, and high water absorption associated with recycled aggregate by incorporating simple treatment to recycled aggregate.

4) Application of recycled aggregate in structural concrete.

5) Reduction in Overall cost of concrete work and saving in project cost.

5. Research Methodology

- Provide treatment to Recycled coarse aggregates.
  (1) Abrasion (2) Cement slurry (3) Chemical
- Investigation of physical and mechanical properties of Recycled Aggregate and Natural aggregate.
- Study of mechanical properties of M-20 Grade of concrete by using different percentage of treated Recycled Aggregate and recycled fine aggregate.
- Finalisation of best suitable treatment methods based on the results
- Finalisation of optimum percentage of coarse and fine recycled aggregate in concrete.
- Study of mechanical properties of M-40, M50 Grade of concrete by using optimum percentage of treated Recycled coarse Aggregate and recycled fine aggregate.
- Use of recycled fine and coarse aggregate in High strength concrete Grade M70.
- Study the stress strain behaviour of recycled aggregate concrete.
- Data analysis and result interpretation to derive conclusions based on objectives of the study.
- Recommendation of fine and coarse RA use in concrete.
Fig. 1 Research Frame Work
6.0 Experimentation and results

Behaviour of the Recycled concrete aggregate is studied experimentally with a special focus on aggregate treatment. These subsequent sections present the details of materials used and the results of experimental study. Experiments were carried out in five stages. In first stage there was preliminary Investigation of materials like Ordinary Portland Cement (OPC) of 53 Grade, Aggregate and sand. The standard tests have been performed to characterize the cement and other materials, results are tabulated. The details of subsequent experiments are mention below.

6.1 Materials

During the experimental study of (Stage –I& II), different material used; **Cement:** Ordinary Portland cement, conforming to Specifications for 53 – grade ordinary Portland cement, (IS:12269, 1987) was used. Specific gravity of cement was found 3.15. **Sand:** The fine aggregate are collected from locally available river, conforming to IS: 383-1970. The Physical properties of river sand determined as per IS 2386 (Part III)-1963. The specific gravity of sand was 2.39 and confirming zone-I. **Natural Aggregate:** Locally available crushed coarse aggregate passing through 20mm and retain on 10 mm IS sieve; conforming to Indian Standard 383-1970 (IS:383-1970, 1970) was used. Specific gravity of natural coarse aggregate was 2.86. **Recycled Aggregates** (RA) was collected from two sources: (a) demolished concrete beam, (demolished for addition and alteration purpose of existing frame structure) age approx less than 05 year. And (b) crushed concrete cubes from laboratory (aged up to 2 year old. laboratory Jaw crusher used for developing RA from broken pieces of RCA, which was initially broke manually. Practical size of RA used in experiments was 20 mm passing 10mm retain. **Recycled fine sand:** In this experimental study Recycled Fine Aggregates (RFA) was residue left at the time of abrasion treatment given to coarse aggregate as well residue left at time of application of jaw crusher for obtaining coarse aggregates. Size of Recycled fine aggregate (RFA) used in experiments was passing from 4.75 mm and retains 150 µ. **Water:** Ordinary tap water available in the laboratory was used for making mixes. The physical and mechanical properties of RA are tabulated in Table 1. The different material used in addition to the described above in (Stage III &IV) For other grade of concrete and high strength concrete of Grade M70, following additional material used in addition to the as described above. **Micro silica:** Micro silica helps to improve concrete in two ways i.e. pozzolanic effect and micro filler effect. For producing M70 grade of concrete,
commercial Micro silica powder was used with a specific Gravity 2.2. Indian standard Silica Fume – Specifications according to IS -15388 (2003), Admixture: The admixture in the form of plasticiser (from a reputed brand) was also used in the present study. MasterRheobuild 823PQ is composed of synthetic polymers specially designed to impart rheoplastic qualities to concrete. Usage of this admixture is limited to **M40 and M50 grade** of concrete. For M70 grade of concrete MasterGlenium SKY 8402, new generation super plasticiser was used. It contains polycarboxylate ether polymers. MasterGlenium SKY 8402 is free of chloride and complies with BS5075 : Part 3 : 1985, its specific gravity is 1.08 and pH-6.5.

![Sample of Recycled fine sand and recycled coarse sand](image)

**Fig .2 Sample of Recycled fine sand and recycled coarse sand**

<table>
<thead>
<tr>
<th>Properties</th>
<th>Natural Aggregate</th>
<th>Recycled aggregate (Without Treatment)</th>
<th>Abrasion treated RA(AT)</th>
<th>Cement Slurry coated RA(CS)</th>
<th>Chemical treated RA(CT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>2.86</td>
<td>2.41</td>
<td>2.48</td>
<td>2.45</td>
<td>2.50</td>
</tr>
<tr>
<td>Water absorption (%)</td>
<td>1.15</td>
<td>9.7</td>
<td>3.92</td>
<td>5.15</td>
<td>6.15</td>
</tr>
<tr>
<td>Crushing Value (%)</td>
<td>24.67</td>
<td>32.95</td>
<td>26.13</td>
<td>28.16</td>
<td>27.13</td>
</tr>
<tr>
<td>Abrasion Value (%)</td>
<td>14.68</td>
<td>24.92</td>
<td>20.46</td>
<td>23.36</td>
<td>25.14</td>
</tr>
</tbody>
</table>
6.2 Methods to Improve Properties of Coarse Recycled Aggregates

In order to improve the quality of RA, several techniques have been developed and available in literature, the main objective is to remove the loose mortar particle on the surface. In this experimental study, three treatment techniques are adopted for improving the quality of RA. (1) Abrasion treatment (AT) (2) Cement Slurry treatment (CST) (3) Chemical treatment (CT).

6.2.1 Abrasion Treatment of RA (AT)

The recycled concrete aggregates used in these experiments were obtained from two sources and were processed in the following steps (1) Manual crushing, (2) crushing with laboratory jaw crusher (3) sieving, aiming at transforming the debris of tested cubes in to aggregates of appropriate size.

In this treatment, coarse recycled aggregate were placed inside Los Angeles abrasion machine. The Rotation of machine was kept at a speed of 25 revolutions per minute for 5 minutes without charge inside.

Several trials in terms of Revolution per minute (RPM) of abrasion machine have been taken for optimization of drum rotation duration. Criteria adopted for selection of Drum rotation duration was Water absorption Percentage of RA after treatment. Trial results show that treated product left after revolution of 5 Min absorbs 3.92% water which is minimum among other trials, hence 5 minute duration adopted for the purpose of treatment of RA. One more criteria under the study was percentage remaining of coarse RA particles after treatment. The results of trials shows that after 5 min revolution of drum ,17.4% of total mass of aggregate fall under the less then 10mm size which was not used as coarse RA in the concrete preparation. However remaining 82.6% of aggregate were used as Coarse Aggregate in concrete. The process chart of aggregate treatment is schematically represented in fig.3.

Table-2 Details of Drum rotation duration and retention of RA %

<table>
<thead>
<tr>
<th>Duration</th>
<th>Water absorption of RA-Without treatment</th>
<th>1 Min.</th>
<th>2 Min.</th>
<th>5 Min.</th>
<th>10 Min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>% left of RA &lt;10 mm size after abrasion treatment</td>
<td>—</td>
<td>4.5%</td>
<td>11%</td>
<td>17.4%</td>
<td>19.5%</td>
</tr>
<tr>
<td>Water absorption % (after duration of treatment)</td>
<td>9.7%</td>
<td>8.6%</td>
<td>7.5%</td>
<td>3.92%</td>
<td>3.96%</td>
</tr>
</tbody>
</table>
Procurement of RCA from two Sources and cleaning

(1) Manual crushing/breaking to make small pieces
(2) Use of Laboratory Jaw crusher for developing RA

Sieving of output from laboratory Jaw crusher

Separation of RA, which are 20 mm passing and 10 mm retain in sieve

Weight of RA inside drum (20 mm passing and 10 mm retain) in a batch = 10 kg

Exp -1 Revolution of Drum for 1 Min. At 25 RPM
Exp -2 Revolution of Drum for 2 Min. At 25 RPM
Exp -3 Revolution of Drum for 5 Min. At 25 RPM
Exp -4 Revolution of Drum for 10 Min. At 25 RPM

Weight of RA, retains after sieve from 20 mm passing and 10 mm sieve.

Reduction in Avg. Weight of RA after Exp 1 = (-4.5%)
Reduction in Avg. Weight of RA after Exp 2 = (-11.04%)
Reduction in Avg. Weight of RA after Exp 3 = (-17.4%)
Reduction in Avg. Weight of RA after Exp 4 = (-19.5%)

Water Absorption of RA after Exp 1 = 8.60%
Water Absorption of RA after Exp 2 = 7.50%
Water Absorption of RA after Exp 3 = 3.92%
Water Absorption of RA after Exp 4 = 3.96%

Fig. 3 Process Flow chart of abrasion treatment of coarse Aggregate
6.2.2 Cement Slurry Treatment of RA (CST)

In this treatment, paste was prepared with cement & water. Cement was taken 10% by weight of water, and was dissolved in water then the mixture was stirred for 10 to 15 minutes to ensure the proper mixing and dispersion. Sample of Recycled coarse aggregate is then soaked in this cement water paste for 24 Hours. Later on the aggregates were drained, arranged on a open tray r vessel, and dried in an oven for 24 h at 105 °C. This dry recycled aggregate was used in concrete preparation.

6.2.3 Chemical Treatment of RA (CT)

The difference between recycled aggregate and natural aggregates is the amount of cement mortar attached on the surface of aggregate. When old concrete is crushed or broken, mortar from the original cement mortar remains attached to the stone particles in the RA, and produces relatively weak layer. For the purpose of removing the mortar that was loosely attached to the original RA, recycled coarse aggregates were pre-soaked in acid for 24 h and then washed with water to remove the acid. The acidic solvents are experimented in this study, namely hydrochloric acid (HCl), with concentration of 0.1 mole.

6.3 Concrete Mix Design

Preparation of all the Concrete mixture batches in this experimental study is as per the IS 10262. All the concrete specimens were cast under laboratory conditions. It was removed from mould 24 h after casting, and then fully submerged in water at 27 °C until further testing.

In this study for proportioning of RA concrete mixes, Indian standard method [IS 10262 (IS 2009)] for natural aggregate is adopted. Mix proportioning was done for M 20 grade concrete with target cube strength of 26.6 MPa at 28 days. The mix proportion (by weight) was arrived at as 1:1.53:3.28, (cement: fine: coarse) with cement content of 388 kg per m³, adopting 0.57 as the water-cement ratio. A concrete mix was prepared in the above proportion using conventional ingredients such as natural coarse aggregate and natural fine aggregate for reference and designated as NAC. Another concrete mix was prepared in the same proportion replacing NA with RA in 10%, 20%, 30% and designated as RAC. Concrete mixes were prepared with Treated RA in same percentage replacement. Mixes is also prepared with fine RA in replacement of
10%, 20%, 30%, 50%, 100 Natural fine aggregate. The total of 19 series of concrete mixes were prepared with difference mix proportion. 150-mm size cubes, 100x100x500mm size of beam and 3-150-mm diameter, 300-mm long cylinders were cast in each of the mix series. These test specimens were cured in water under laboratory conditions until the age of testing. The compressive strength of the cube specimen was determined at 7, 28, days of age. Splitting tensile strength and flexural strength were conducted at 7 and 28 days of age.

For M 40 and M50 grade of concrete, Indian standard method [IS 10262 (IS 2009)] applicable for natural aggregate is adopted for the mix design. Maximum size of aggregate taken is 20mm and grading of sand is zone I. The quantity of materials required for 1m³ of conventional M40, M50 and M70 concrete mix are given Table 3. In this experimental study, 10, 20 and 30%, replacement of RA by weight of the total coarse aggregate content was used. In addition to coarse RA replacement fine RA is also replaced with 30 and 50% with natural sand. These batches were distinguished by the different % replacement of coarse RA and fine RA.

For high strength concrete preparation, Preliminary studies have been done in cement mortar cubes with different proportions of natural ingredients to develop mix proportion for M70 grade of concrete. During this trial mix micro silica were used along with natural ingredients. During trail mix for developing desire workability in control concrete different percentage in the range of 0.5 % to 1 % dosage of admixture was used. Final mix proportion for normal concrete mix is shown in Table-3.

<table>
<thead>
<tr>
<th>Grade of Concrete</th>
<th>Material in Kg per m³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cement</td>
</tr>
<tr>
<td>M20</td>
<td>388</td>
</tr>
<tr>
<td>M40</td>
<td>445</td>
</tr>
<tr>
<td>M50</td>
<td>490</td>
</tr>
<tr>
<td>M70</td>
<td>450</td>
</tr>
</tbody>
</table>
6.3.1 Specimen Label

NA stands for control concrete prepared with natural aggregate and natural sand. RA10, RA20, RA30 indicate concrete prepared with 10%, 20%, 30% replacement of untreated coarse recycled aggregate. Letter “T” indicates treatment given to coarse RA. RA10T means 10% treated coarse RA replacement. Likewise RA20T and RA30T is 20 % and 30 % replacement of treated coarse RA. RA10T FRA10 means 10% treated coarse RA replacement with 10 % fine RA replacement to the natural ingredients. Same as in case of RA10T FRA30, RA10T FRA50, RA10T FRA100 and so on. FRA indicates fine recycled aggregate with its percentage replacement.

6.4 Results and Discussion

The summary of the test results regarding the Strength properties test specimens like their capacity result interpretation and comparison are introduced through this section.

6.4.1 Workability Measurement by Slump Test

Workability by slump cone was determined by using Methods of Sampling and Analysis of Concrete (IS:1199, 1959) for RA concrete mixes. For the purpose of examining fresh properties of recycled aggregate concrete (RAC), Concrete mixes were prepared by replacing 10%, 20%, 30% coarse RA with and without Treatment. Concrete with Abrasion treated RA designates as RAC(AT) similarly RAC(CST) is concrete with cement slurry treated aggregate. In above concrete mix there were also replacement of fine aggregate with fine recycle aggregate in proportion of 10%,30%,50%&100% . Concrete mix was prepared with combination of coarse treated recycle aggregate and fine recycled aggregate, replacement of coarse RA was restricted to 30%. All the results of slump test are shown below in fig.4. it can be observed that Coarse RA-10,20,30% Replacement- exhibits workable concrete which is at par with NAC ,fine RA-10,30,50,100% Replacement- Shows stiff concrete-One of the key point observed here that when fine recycled aggregate is used at higher percentages (i.e. 30%,50%and 100%), the concrete mixes were less cohesive than those prepared with natural aggregates.
In Concrete Grade M40 and M50, it was observed that there was no significant change in the slump of concrete when recycled coarse and fine aggregate were used with admixture. 1.0% of cement weight of super plasticizer was used in all mixtures following manufacturer’s recommendations. The results of variations of concrete slump carried out on fresh concrete are shown in figure 5. The slump value for the mix prepared with natural coarse aggregate was 80mm which was less than the target slump of 90 mm. Fig shows that the slump values of various replacement of coarse and fine RA, It can be seen that, except 30% coarse RA and 50% fine RA all other mixes, were within a narrow range of the target slump. Decrease in slump might be due to the moisture state of different types of coarse aggregate and increased surface roughness and angularity with generations.
6.4.2 Determination of Compressive Strength of Recycled Aggregate Concrete

The compressive strength for M20 grade of concrete were determined as per IS 516-1959 (IS 1959), using a compression machine with a loading capacity of 3,000 kN. The compressive strength was determined with cube specimen of 150x150x150 mm size. The specimens were cured in water for 7-days, and 28-days. 7 day and 28 day the cube compressive strength is calculated as crushing load per unit area and is presented in Table 4. To understand the influence of the coarse and fine aggregate replacement ratio on the compressive strength of concrete at 28 days, Fig. 7 shows the test results. The Comparison of 28 day Compressive strength between RAC (AT) and RAC (CST) also shown in fig.5. From this figure, it is seen that the 28 days compressive strength of RAC (AT) with 30% replacement is 27% higher of RAC(CST) and 14% higher to NAC. This increase in strength is due to effective removal of the adhered mortar. The 28 days compressive strengths of mixes prepared RAC(AT) in simultaneous use of fine RA 50% are is increase up to 33 % compare to NAC. The improvement in compressive strength is also due to higher density aggregates, which ultimately leads to higher strengths. this higher efficiency achieve with simple abrasion technique. This technique gives quality aggregates with better properties such as reduced water absorption due to efficient removal of adhered mortar.
Table 4  Compressive Strength of Recycled Aggregate Concrete

<table>
<thead>
<tr>
<th>Serial numbers</th>
<th>Mix series</th>
<th>Mix series</th>
<th>Compressive Strength RAC(AT) 7 days</th>
<th>Compressive strength RAC(CST) 28 days</th>
<th>Compressive strength RAC(CT) 28 days</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>NA</td>
<td>18.05 29.78</td>
<td>18.05 29.78</td>
<td>29.78</td>
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<tr>
<td>2</td>
<td>B</td>
<td>RA10</td>
<td>21.10 30.28</td>
<td>17.53 28.32</td>
<td>30.28</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>RA20</td>
<td>21.70 31.61</td>
<td>17.76 27.21</td>
<td>31.61</td>
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<tr>
<td>4</td>
<td>D</td>
<td>RA30</td>
<td>20.60 30.86</td>
<td>14.44 26.88</td>
<td>30.86</td>
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<td>5</td>
<td>E</td>
<td>RA10T</td>
<td>21.96 30.78</td>
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<td>30.58</td>
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<td>8</td>
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<td>RA10T FRA10</td>
<td>22.12 36.31</td>
<td>16.08 22.67</td>
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<td>22.30 30.23</td>
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<td>31.08</td>
</tr>
<tr>
<td>10</td>
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<td>RA10T FRA50</td>
<td>24.96 36.88</td>
<td>18.02 24.02</td>
<td>32.08</td>
</tr>
<tr>
<td>11</td>
<td>K</td>
<td>RA10T FRA100</td>
<td>28.56 32.94</td>
<td>19.10 25.70</td>
<td>32.05</td>
</tr>
<tr>
<td>12</td>
<td>L</td>
<td>RA20T FRA10</td>
<td>23.39 35.73</td>
<td>20.73 28.18</td>
<td>32.86</td>
</tr>
<tr>
<td>13</td>
<td>M</td>
<td>RA20T FRA30</td>
<td>23.69 34.66</td>
<td>21.88 28.85</td>
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<td>14</td>
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</tr>
<tr>
<td>15</td>
<td>O</td>
<td>RA20T FRA100</td>
<td>24.46 30.69</td>
<td>22.97 30.59</td>
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</tr>
<tr>
<td>16</td>
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<td>24.91 32.45</td>
<td>30.05</td>
</tr>
<tr>
<td>17</td>
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<td>RA30T FRA30</td>
<td>24.75 34.34</td>
<td>25.65 34.64</td>
<td>33.25</td>
</tr>
<tr>
<td>18</td>
<td>R</td>
<td>RA30T FRA50</td>
<td>26.11 39.73</td>
<td>26.27 36.81</td>
<td>27.05</td>
</tr>
<tr>
<td>19</td>
<td>S</td>
<td>RA30TFRA100</td>
<td>27.57 33.7</td>
<td>26.82 37.22</td>
<td>27.55</td>
</tr>
</tbody>
</table>
For M40 and M50 grade of concrete, the properties of the concrete prepared with treated RCA and fine RA were analyzed and then compared with those of the control concrete samples with untreated RCA. In M40 and M50 grade of concrete 9 concrete mixes prepared. In each series of mix 150-mm size cubes used for compressive strength measurement, 150-mm diameter, 300-mm long cylinders were used for splitting tensile strength and for determination of flexural strength 10x10x50 cm size specimen was used for cast in each of the mix series. These test specimens were cured in water under laboratory conditions until the age of testing. The compressive strength, flexural strength and splitting tensile strength of the specimen were determined at 28, days of age.

The compressive strength results for the concrete mixtures for M40 and M50 grade concrete is presented in figure. All recycled concrete mixtures obtained a higher compressive strength in comparison to those of the control concrete which is prepared with natural ingredients., except for M40-concrete made with replacement of 30 % coarse recycled aggregate with 50% fine RA which obtained 10% lower strength.
6.4.3 High Strength Recycled Aggregate Concrete

High strength concretes was produced using fine aggregates (RFA) in substitution of 30% and 50% of natural sand, and using 10%, 20% and 30% of treated coarse recycled aggregates (AT) on substitution of natural coarse aggregates. The Compressive strength of recycled aggregate concretes were determined and compared to those of the results of conventional concrete.

6.4.4 Strength Measurement

Fig 8 shows the variation of compressive strength due to replacement of coarse and fine recycled aggregate at the age of 28 days. The target compressive strength of M70 is 78.25 N/mm2. From the result, it was observed that the concrete mixes in all cases is above the target mean strength which is 78.25 MPa. However concrete made with 10% Coarse RA and 50% fine RA exhibits strength which is close to Natural concrete. Concrete prepared with 30% coarse
RA and 50% Fine RA shows 5% less compressive strength reference to control concrete, however strength is more than 5.5% to target strength.

Fig. 8 Compressive strength of M70 Grade of concrete
6.5 Flexural Strength and Splitting Tensile Strength Of RAC

In order to study the flexural strength and splitting tensile strength of concrete (M20) of Grade with different replacement percentage of recycled coarse aggregate and fine aggregate, the test were designed and carried out on above 19 concrete mixes. Flexural strength test is done as per IS: 516-1959. The size of beam specimens for flexural tensile strength was 100x100x500 mm. The specimens were cured in water for 7-days, and 28-days. Flexure strength test, the beam specimen is simply supported on two rollers of 4.5 cm diameter. The flexural tensile strength is calculated as the ratio of the calculated bending moment and section modulus of the beam specimen. The Tensile test set-up and flexure test set up is shown in fig.9 Split tensile strength of concrete was performed as per IS 5816-1999. Cylinders of 150mm diameter and 300mm length were casted. The samples were cured for 28 days. The tensile test is conducted on compression testing machine of capacity 3000 KN. Results of splitting tensile strength and flexural strength for Strength of Grade M20 are shown in Table-4 for various concrete mixes.

![Fig. 9 Tensile Strength Test and flexure strength test.](image-url)
Table 5  Result of Flexural strength and splitting tensile strength of RAC

<table>
<thead>
<tr>
<th>Mix series</th>
<th>Mix series</th>
<th>28 days Tensile strength RAC(AT)</th>
<th>28 days Tensile strength RAC(CST)</th>
<th>28 days Flexural strength RAC(AT)</th>
<th>28 days Flexural strength RAC(CST)</th>
<th>28 days Tensile strength RAC(CT)</th>
<th>28 days Flexural strength RAC(CT)</th>
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<tbody>
<tr>
<td>A</td>
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<td>2.29</td>
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<td>5.73</td>
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<td>1.83</td>
<td>4.82</td>
<td>4.76</td>
<td>1.95</td>
<td>4.82</td>
</tr>
<tr>
<td>D</td>
<td>RA30</td>
<td>2.10</td>
<td>1.71</td>
<td>4.20</td>
<td>4.06</td>
<td>2.10</td>
<td>4.20</td>
</tr>
<tr>
<td>E</td>
<td>RA10T</td>
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<td>1.97</td>
<td>5.40</td>
<td>5.36</td>
<td>1.98</td>
<td>5.33</td>
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<tr>
<td>F</td>
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<td>3.89</td>
<td>1.99</td>
<td>5.37</td>
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<tr>
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<td>RA10T FRA30</td>
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<td>2.98</td>
<td>4.10</td>
<td>3.93</td>
<td>2.01</td>
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<tr>
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<td>3.02</td>
<td>4.15</td>
<td>3.96</td>
<td>2.10</td>
<td>5.50</td>
</tr>
<tr>
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<td>3.30</td>
<td>3.18</td>
<td>4.22</td>
<td>4.11</td>
<td>1.99</td>
<td>5.30</td>
</tr>
<tr>
<td>L</td>
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<td>3.40</td>
<td>4.35</td>
<td>4.29</td>
<td>1.99</td>
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</tr>
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<td>RA20T FRA30</td>
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<td>4.56</td>
<td>4.31</td>
<td>1.99</td>
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<td>4.86</td>
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<td>4.90</td>
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<td>4.85</td>
</tr>
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<td>3.98</td>
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<td>5.20</td>
<td>5.03</td>
<td>2.26</td>
<td>5.20</td>
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</table>

Figure 10 and 11 shows splitting tensile strengths and flexural strength for M40 and M50 Grade concretes. The concretes made with recycled aggregate achieved a similar or marginal less flexural and splitting strength to those of the control concrete, especially in case of 50% replacement of fine aggregate. The use of recycled fine aggregate substitution of natural fine aggregates for concrete production had a negative influence on those properties. Only the concrete made with 30% of fine RA obtained or at par flexural strength to that of Control concrete.
Fig. 10 Flexural strength for M40&M50 Grade

Fig. 11 Tensile Strength for M40&M50 Grade
6.6 Stress Strain Behaviour Recycled Aggregate Concrete.

Concrete is not a true elastic material but it shows non linear behaviour between the stresses and strains. The modulus of elasticity establish from experimental load is called static modulus of elasticity. The method of determining the modulus of elasticity is to measure with initial tangent modulus, which is defined as the slope of the tangent drawn to the stress-strain curve. It is to be determined with cylindrical specimen 150x300mm. The elastic modulus of concrete is one of the most important mechanical factors reflecting ability of concrete to deform elastically. For evaluating the modulus of elasticity of concrete according to the IS 516-1959, the test specimen shall be a cylindrical specimen of size 150x300mm and the ratio of height/diameter is kept as 2.0. Six specimens were cast for each grade with replacement of 30% coarse aggregate and 50% fine aggregate replacement.

6.6.1 Behaviour Of Cylinder Under Compression

Out of six specimens, three specimens were tested for determining the ultimate compressive strength of cylindrical specimen and remaining three were used for determining the strain. It can be observed from Table 6, the 28 days cylindrical compressive strength less compare to cube compressive strength. The reason for this is due to more contact area of cube specimen with top arm of the compressive testing machine and resistant against the expansion of cylindrical specimen. Elastic characteristic of a material is measure of its stiffness. In spite of non linear behaviour of concrete, an estimate of the modulus of elasticity is necessary for determining the stresses induced by strains associated with environmental effects. Test results of modulus of elasticity for Recycled aggregate concrete are presented in fig. 17 Modulus of Elasticity EC = 5000 $\sqrt{f_{ck}}$, (fck is characteristic strength of concrete) - As per the IS456-2000.
Table 6  Compressive strength of cylindrical specimen and Cub specimen

<table>
<thead>
<tr>
<th>Sr no</th>
<th>Mix</th>
<th>Grade of Concrete</th>
<th>Compressive strength of Cylinders in MPa</th>
<th>Compressive strength of Cubes in MPa</th>
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</thead>
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<td>1</td>
<td>NAC</td>
<td>M20</td>
<td>26.80</td>
<td>29.78</td>
</tr>
<tr>
<td>2</td>
<td>RA30TFRA50</td>
<td>M20</td>
<td>26.85</td>
<td>33.15</td>
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<tr>
<td>3</td>
<td>NAC</td>
<td>M40</td>
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<td>51.63</td>
</tr>
<tr>
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<td>RA30TFRA50</td>
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<td>39.77</td>
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<tr>
<td>5</td>
<td>NAC</td>
<td>M50</td>
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</tr>
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<td>M70</td>
<td>60.26</td>
<td>82.56</td>
</tr>
</tbody>
</table>

Experimental values of elasticity modulus are marginal, compared with IS Code provisions. Hence, it is concluded that, Recycled aggregate is acceptable to replace the natural coarse aggregate. The Fig 13, 14, representing the Stress vs. strain with respect to different grade of concrete. With reference to natural aggregate concrete and recycled aggregate concrete.
Fig. 13  Stress Vs Strain For NAC & RAC-M20,M50

Fig. 15  Stress Vs Strain for NAC & RAC-M70
7.0 Achievements with Respect to Objectives

The following enlisted are the main contributions of this Research:

1. Concrete made from proposed abrasion treatment of recycled aggregate performed well in comparison to strength performance of RAC of other type of treatment of aggregate.

2. The present study confirms that partial replacement with coarse and fine recycled aggregate can produce strength comparable to NAC in M20, M40, M50 and M70 grade of concrete.

3. The stress versus strain relationship of the concrete incorporating fine and coarse recycled aggregate is found comparable to concrete with natural aggregates.

8.0 Conclusions

The main findings of this investigation can be summarized as follows:

Experiments on reused aggregates have demonstrated that good quality concrete can be created with coarse and fine reused aggregates.

(1) The compressive strength of recycled aggregate concrete with 30% replacement of coarse aggregate is at par with natural aggregate concrete. The compressive strength of recycled aggregate concretes after abrasion treatment, acid treatment and cement slurry treatment was found comparable to strength of natural aggregate concrete.

(2) Abrasion treatment of recycled aggregate is more efficient and suitable than chemical and cement slurry treatment in removing the attached mortar and improving performance of recycled aggregate.

(3) The use of 50% of fine recycled aggregates and 30% of coarse recycled aggregate replacement, gives comparable 28 days compressive strength and tensile strength of conventional concrete in concrete grades M20, M40, M50 and M70.

(4) The workability of recycled aggregate concrete mix is lower than natural aggregate concrete. In case of concrete mix with only 30% treated coarse recycled aggregate concrete has produced satisfactory workable concrete. However by adding super plasticizer, workability of concrete with 30% coarse recycled and 50% fine recycled aggregate becomes comparable to that of conventional concrete with natural aggregates.
In comparison to the theoretical value given in IS 456, Experimental elastic modulus for natural aggregate concrete is at par with code value. However the values are marginally less in M20, M40 and M50 grades for concrete containing 30% recycled coarse aggregates and 50% fine recycled aggregate which is still higher than that derived by BS and ACI. The experimental value of modulus of elasticity in natural aggregate concrete and recycled aggregate concrete is higher than the theoretical modulus of elasticity of concrete calculated by British code (BS-8110) and ACI.

Making use of recycled aggregates material over natural materials can save money to certain extent, 10% cost benefit can be achieved in this region

9.0 Publications


4. V. P Kukadia,Dr.R.K.Gajjar,Dr.D.N.Parekh, Mechanical strength properties of concrete containing treated coarse recycled concrete aggregates and recycled fine aggregate, 33rd National Convention of Civil engineers, The institution of Engineers (India),Gujarat state center , 02-03-september 2017.

Papers in Communication

1. Vijay. P. Kukadia, Prof(Dr). R.K.Gajjar, Dr.D.N.Parkeh, Experimental Study of Concrete Prepared With Fine Recycle Aggregate and Treated Coarse Recycle Aggregate, International Journal of Materials and Structural Integrity -(IJMSI is indexed in: Scopus (Elsevier)
10. References


