A Study on Properties of Concrete, using Recycled Coarse Aggregate

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Abstract:
Expected life of RCC building, considered to be 50 – 60 years and many RCC structures all over the world are now reaching the end of their design life. Demolition or maintenance work on such structures results in large amount of building waste especially concrete waste. Disposal of such waste is becoming a severe environmental problem. To minimize this issue the usage of recycled coarse aggregate (RCA) to partially replace natural coarse aggregate (NCA) is slowly accepting by the people. RCA made from waste concrete has high water absorption due to the cement mortar attachment, which generally leads to concrete with inferior strength and durability. A study was conducted by applying a coating for the surface of RCA, using Polycarboxylate Ether (PCE), a water soluble plasticizer and found that, the water absorption of surface coated recycled course aggregate (SCRCA) reduced considerably. Also given better results in slump test for consistency, and compressive test for its strength.

Keywords: Recycled course aggregate (RCA), Surface coated Recycled course aggregate (SCRCA), Polycarboxylate Ether (PCE), Concrete with Recycled Aggregate, Reduction in Water absorption of RCA.

I. INTRODUCTION

A. General
Many structures that were constructed after middle of 20th century are now in need of either major repairs or possible replacement. This is because some of such structures are now reaching the end of their design life, may not have been constructed according to the specifications, or did not receive the required maintenance while in service. The repair and replacement activities result in large quantities of construction waste. Previously this waste were used for landfill, but due to the shortage of sufficient suitable land in urban areas, and environmental awareness, waste disposal is becoming a headache for almost all developed and under developing countries. Parameters like environmental consciousness, protection of natural resources, sustainable development, play an important role in modern requirements for construction works. In other hand, traditionally aggregates have been readily available at economic price. However, in recent years the wisdom of our continued wholesale extraction and use of aggregates from natural resources has been questioned at an international level. This is mainly because of the depletion of quality primary aggregates and greater awareness of environmental protection. In light of this, the availability of natural resources to future generations has also been realized. Given this background, the concept of sustainable development put forward almost a decade ago, at the 1992 Earth Summit in Rio de Janeiro, and it has become a guiding principle for the construction industry worldwide. In fact many governments throughout the world have now introduced various measures aimed at reducing the use of primary aggregates and increasing reuse and recycling, where it is technically, economically, or environmentally acceptable. For example, the UK government has introduced a number of policies to encourage wider use of secondary and recycled course aggregate (RCA –defined as minimum of 95% crushed concrete) as an alternative to naturally occurring primary aggregates. These include landfill and future extraction taxes to improve economic viability, support to relevant and development work.

B. Need to use recycled coarse aggregate (RCA)
The demand of aggregates by the global concrete industry was 12 billion tones per year after 2010 (Keun-Hyeok et al., 2008). This itself increasing at much faster rate in 2019 due to the modernization of cities, rehabilitation of old buildings, etc. Natural aggregates are usually obtained by mining only, and cannot be manufactured through industries. As the natural sources are not increasing, but the demand is highly increasing, so it is an urgent need to find the sustainable solution to get an alternative of natural aggregate. On the other hand, waste arising from construction and demolition, constitutes one of the largest waste streams within the European Union (EU)[1], Asian and many other countries. For example, it is estimated that core waste (described as those types of materials which are obtained from demolished building or civil engineering infrastructure) amounts to around 180 million tones per year or 480 kg/person/year in the EU. Another recent study undertaken by the CSIR Building and Construction Technology has revealed that nearly a million tone of construction and demolition waste ends up in landfills in South Africa. This is in addition to large quantities that are dumped illegally. Also the concrete is the third largest contributor to Carbon dioxide emissions, after automobiles & coal-fueled power plants. Cement manufacturing alone is responsible for roughly 5% of global CO₂ emissions. Concrete also makes up the largest proportion of construction and demolition waste, and represents a third of all landfill waste. This has serious repercussions for the planet and requires sustainable solution. It is now widely accepted that there is a significant potential for reclaiming and recycling demolished debris for use in value added applications to maximize economic
and environmental benefits. As a result of this, recycling industries in many part of the world including India, at present converts low- value waste into secondary construction materials such as a variety of aggregate grades, road materials and aggregate fines. Often these materials are used in road construction, backfill for retaining walls, low grade concrete production, manufacturing for cement solid blocks, etc. The aim of sustainable development is followed and consequently, the basis for a friendly co-existence of man and nature is set. While accepting the need to promote the use of RCA in wider applications, it must be remembered that the aggregate for concrete applications must meet the requirements set in relevant specifications for its particular use.

C. Limitations of RCA
In recycled concrete, the reclaimed concrete used to make coarse aggregate for new concrete may come from different sources. It can be obtained through the demolition of concrete elements of roads, bridges, buildings and other structures, or it can come from the residue of fresh and hardened rejected units in precast concrete plants. Its physical characteristics and strength are worse than those of natural aggregate. The quality of the recycled concrete aggregate will normally vary depending on the properties of the recovered concrete. Variations between concrete types result from differences in aggregate quality, aggregate size and texture, concrete compressive strength, and uniformity. Therefore, there is a need to investigate the effect of the origin of the RCA on the strength properties of the new concrete. Specifically, it is desired to quantify the consequences of using RCA with lower, equal, or higher strength than the target strength of the new concrete.

D. Objectives of the study
The objectives of the study are to investigate the following.

- To eliminate the construction and demolition waste
- To reduce carbon emission
- To determine the factors that influence the compressive and tensile strengths of concrete using recycled coarse aggregate.
- To investigate the improvements in the properties of concrete using surface coated RCA

E. Methodology
Concrete waste collected from old RCC building demolishing site and the sample was 40 years above old. The sample crushed by manual process and the course aggregate separated from fine aggregate through Sieve analysis. (4.75 - 10mm and 10-20mm size were used). Then several experiments conducted using the above recycled coarse aggregate(RCA)in different proportion with natural coarse aggregate(NCA)for M20 concrete. In order to compare results objectively, a control mix also made from natural coarse aggregate is needed to benchmark the results. The effect of water absorption of RCA on the microstructure (interfacial transition zone), mechanical properties (compressive strength, and modulus of elasticity), of the resulting RCA concrete was investigated. Then the surface of RCA was given with a coating of Super plasticizer (Polycarboxylate Ether) so as to reduce its water absorption

2. LITERATURE REVIEW
RCA use will influence high water absorption of recycled aggregate, of concrete (Fumoto and Yamada, 2006). This is due to the migration of water absorbed by the aggregate to the paste around particles of aggregate, then the water absorption will influence volume of water and pores in the paste. Increasing the level of cleanliness of RCA, in terms of the amount of mortar adhering to aggregate particles, has been found to improve the workability, mass per unit volume and compressive strength of the concrete and to reduce the air content (Montgomery and Sturgiss, 1996).

J.S. Ryou, and Y.S.Lee (2014) In this study, to improve the performance of RCA and to reduce its absorption, its surface was coated with Polycarboxylate(PC) dispersant. To verify the efficiency of such technique, the slump and air content losses of fresh concrete in this study evaluated based on the elapsed time.

Mirjana Malesev et al (2010) insisted that the workability of concrete with natural and recycled aggregate is almost the same if water saturated surface dry recycled aggregate is used. Also, if dried recycled aggregate is used and additional water quantity is added during mixing, the same workability can be achieved after prescribed time. Bulk density of fresh concrete is slightly decreased with increase in the quantity of recycled aggregate.

Hansen and Narud (1983) found that the compressive strength of recycled concrete is strongly correlated with the water-cement ratio of the original concrete if other factors are kept the same. When the water-cement ratio of the original concrete is the same or lower than that of recycled concrete, the new strength will be as good as or better than the original strength, and vice versa. Later in 1984, Hansen and Hedegkd showed that the addition of a plasticizing, an air entraining, a retarding, and an accelerating admixture to the original concrete had little or no effect on the properties of recycled concrete[15].

In a study by Sagoe-Crentsil and Brown (1998), it was found that the processing of recycled concrete aggregates commercially produces smoother spherical particles than those produced in the laboratory, which improves concrete workability. Tests on the compressive and tensile strengths of hardened concrete showed no significant difference between recycled concrete and concrete made with natural aggregates. Investigation of the durability indicated that the recycled aggregates caused a higher drying shrinkage values and reduced the abrasion resistance by about 12%. The water absorption and carbonation rates showed little difference between the recycled concrete and conventional one.

Gomez-Soberon (2002).studied the porosity of recycled concrete made with substitution of recycled concrete aggregate. The distribution of the theoretical pore radius, critical pore ratio, surface area of concrete, threshold ratio, and average pore ratio were investigated at 7, 28, and 90 days. The results showed that porosity increases when natural aggregate is replaced by recycled concrete aggregate. The increase in porosity is accompanied by a reduction in compressive and tensile strengths, as well as in modulus of elastic

3. MATERIAL PROPERTIES
A. Introduction
Demolished structural elements were selected to produce RCA, and it was collected from a demolishing site of a RCC building
aged 40 years, near Tripoonithura, Ernakulam. The concrete blocks collected were crushed by manually into the required size and grading according to IS 2386 (1963). The natural coarse aggregate (NCA) was collected from a granite quarry near Kolenchery, Ernakulam. In general, RCA was found to be coarser, porous, and rougher, compared to NA. The main physical and mechanical characteristics of RCA and NCA are given in Table 1. It can be seen that RCA had 7 to 9% lower relative density and two times higher water absorption than NCA, reflecting the porosity of the hydrated cement paste attached to RCA. The mechanical properties of RCA, were found to be lower than NCA.

B. Binding material- Cement
In this study, the cement used was Grade53, Ordinary Portland Cement conforming to IS 12269: 1987[3]. The physical properties of cement are shown in Table 1

<table>
<thead>
<tr>
<th>S.no</th>
<th>Properties</th>
<th>Value</th>
<th>IS specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Specific gravity</td>
<td>3.15</td>
<td>IS:4031</td>
</tr>
<tr>
<td>2</td>
<td>Standard consistency</td>
<td>34%</td>
<td>IS:4031 &amp; IS:269</td>
</tr>
<tr>
<td>3</td>
<td>Initial setting time (min)</td>
<td>121</td>
<td>&gt;30, IS:4031 &amp; IS:269</td>
</tr>
<tr>
<td>4</td>
<td>Final setting time (min)</td>
<td>380</td>
<td>&lt;600, IS:4031 &amp; IS:269</td>
</tr>
</tbody>
</table>

C. Fine Aggregate
Manufactured sand (M-sand) was used as fine aggregate conforming to zone II and it is shown in Fig 1. a) Specific gravity: The Specific gravity of fine aggregate was found by Pycnometer and the experiment was done as per IS 2386-3:1963[4]. The Specific gravity of fine aggregate obtained as 2.71

Figure 1. Natural coarse aggregate

b) Water absorption:
Water absorption is defined as the percentage of water absorbed by an aggregate when immersed in water. Water absorption was calculated according to IS 2386 (3) 1963. The water absorption of natural fine aggregate was obtained as 11.20%.

c) Sieve analysis:
Sieve analysis of fine aggregate is done in order to find out the particle size distribution of the aggregate and according to it, the grading of aggregates can be done. According to sieve analysis, the fineness modulus (FM) is found out and it is a ready index of coarseness or fineness of the material. The test was conducted according to IS 2386(1):1963. The results obtained from sieve analysis are shown in Table 2

<table>
<thead>
<tr>
<th>Sieve (mm)</th>
<th>Weight retained (gm)</th>
<th>% of weight retained</th>
<th>Cumulative % weight retained</th>
<th>% of finer</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>4.75</td>
<td>7</td>
<td>0.7</td>
<td>0.7</td>
<td>99.3</td>
</tr>
<tr>
<td>2.36</td>
<td>240</td>
<td>24.0</td>
<td>24.7</td>
<td>75.3</td>
</tr>
<tr>
<td>1.18</td>
<td>232</td>
<td>23.2</td>
<td>47.9</td>
<td>52.1</td>
</tr>
<tr>
<td>0.6</td>
<td>171</td>
<td>17.1</td>
<td>65.0</td>
<td>35.0</td>
</tr>
<tr>
<td>0.3</td>
<td>139</td>
<td>13.9</td>
<td>78.9</td>
<td>21.1</td>
</tr>
<tr>
<td>0.15</td>
<td>103</td>
<td>10.3</td>
<td>89.2</td>
<td>10.8</td>
</tr>
<tr>
<td>Pan</td>
<td>108</td>
<td>10.8</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>

D. Natural coarse aggregate (NCA)
Granite aggregate particles passing through 20mm and retained on 4.75mm IS sieve was used as NCA. Course aggregate contributes significantly to the structural performance of concrete, especially strength, durability, and volume stability. It occupies more than 70% of the volume of concrete.

a) Specific gravity:
The test was conducted as per IS 2386-3:1963[3], and the value of specific gravity of NCA is 2.68. According to M S Shetty, in concrete Technology, the average specific gravity of natural granite varies from 2.6 to 2.8.

b) Water absorption:
Water absorption is defined as the percentage of water absorbed by an aggregate when immersed in water. Water absorption was calculated according to IS: 2386 (3) 1963[4].

Water absorption of aggregate 20 -12 = 1.83%
Water absorption of aggregate 2 - 4.75 = 1.95%

Sieve analysis: Sieve analysis of coarse aggregate is done in order to find out the particle size distribution of the aggregate and according to it, the grading of aggregates can be done. The sieve analysis is done as per IS:2386(Part i)-1970[4]. The results obtained from the sieve analysis are shown in Table 3

<table>
<thead>
<tr>
<th>Sieve (mm)</th>
<th>Weight retained (gm)</th>
<th>% of weight retained</th>
<th>Cumulative % weight retained</th>
<th>% of finer</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>12</td>
<td>150</td>
<td>15</td>
<td>15</td>
<td>85</td>
</tr>
<tr>
<td>10</td>
<td>235</td>
<td>23.5</td>
<td>38.5</td>
<td>61.5</td>
</tr>
<tr>
<td>4.75</td>
<td>490</td>
<td>49</td>
<td>87.5</td>
<td>12.5</td>
</tr>
<tr>
<td>0.6</td>
<td>95</td>
<td>9.5</td>
<td>97</td>
<td>3</td>
</tr>
<tr>
<td>0.15</td>
<td>10</td>
<td>1</td>
<td>98</td>
<td>2</td>
</tr>
<tr>
<td>Pan</td>
<td>20</td>
<td>2</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>

E. Recycled Coarse Aggregate (RCA)
The recycled coarse aggregate passing through 20mm and retained on 4.75mm IS sieve were used as RCA as shown in Fig 2.
Figure 2. Recycled Course aggregate

**a) Specific gravity**
Test was conducted as per IS:2386(3)-1963[3], and the value of specific gravity of RCA was 2.34

**b) Water absorption**
Water absorption is defined as the percentage of water absorbed by an aggregate when immersed in water. The water absorption of RCA was found according to IS:2386(3)-1963[4]

Water absorption of aggregate 20 -12 = 7.2%
Water absorption of aggregate 12 -4.75 = 7.4%

**c) Sieve analysis**
Sieve analysis of RCA was done in order to find out the particle size distribution of the aggregates and according to it, grading of aggregates can be done. The sieve analysis is done as per IS :383-1970[4]. The particle size distribution is shown in Table 4

<table>
<thead>
<tr>
<th>Sieve (mm)</th>
<th>Weight retained (gm)</th>
<th>% of weight retained</th>
<th>Cumulative % weight retained</th>
<th>% of finer</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>12</td>
<td>140</td>
<td>14</td>
<td>14</td>
<td>85</td>
</tr>
<tr>
<td>10</td>
<td>225</td>
<td>22.5</td>
<td>36.5</td>
<td>61.5</td>
</tr>
<tr>
<td>4.75</td>
<td>505</td>
<td>50.5</td>
<td>87</td>
<td>12.5</td>
</tr>
<tr>
<td>0.6</td>
<td>90</td>
<td>9</td>
<td>96</td>
<td>3</td>
</tr>
<tr>
<td>0.15</td>
<td>12</td>
<td>1.2</td>
<td>97.2</td>
<td>2</td>
</tr>
<tr>
<td>Pan</td>
<td>28</td>
<td>2.8</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>

**Table 4. Sieve analysis of Recycled Course Aggregate**

F. Polycarboxylate Ether ((PCE) Super Plasticizer
Polycarboxylate Ether (PCE) is a super plasticizer generally used for water reduction in concrete and for producing cohesive and non-segregating concrete mixtures. It is available in liquid form with deep brown colour as shown in the Fig. 3. This Super plasticizer was used for the study of RCA with surface coating.

Specification of Polycarboxysulphate:
Appearance: Deep brown colored liquid
pH value(1:10): 5.0 ± 0.5
Solubility: Readily soluble in water
Solid part: 50 ± 2%
Specific Gravity: 1.110 ± 0.02
Chloride content: Below 0.02

G. Water
Portable water available in laboratory was used for mixing and curing the concrete specimens.

3.8. Pre Soaking Treatment
The recycled aggregates were crushed and soaked in water for 24 hours for water treatment then kept for drying.

4. EXPERIMENTAL STUDY

A. Introduction
In order to compare results objectively, a control mix made from natural coarse aggregate is needed to benchmark the results. All tests were conducted for M20 using different proportions of RCA coated with a super plasticizer –Polycarboxylate Ether (PCE). Mechanical properties of the concrete were tested for 7 days & 28 days target strengths. The tests were conducted with different proportion of coated RCA, such as 0%, 25%, 50%, and 100% replacement.

B. Effect of surface coating:
Water absorption for the sample of RCA was 7.2 to 7.4, and for NCA, it was 1.83 to 1.95. But after the surface coating of RCA with PCE, the water absorption became 3.2 to 3.6. Moreover, after mixing, the water soluble PCE controlled the slump loss. Early water absorption was prevented at mixing, and the water contents needed for chemical action was reduced because the PCE dispersed the cement particle.

C. Experiments
From the previous studies it is understood that the water absorption rate of RCA was almost 3 times more than that of NCA. It shows in the test results, the density of RCA also lower than NCA. In this study, we have made an attempt to reduce the water absorption of course aggregate by giving a surface coating using a super plasticizer –Polycarboxylate Ether (PCE). Actually PCE is used in the construction industry as a plasticizer. RCA sample is dumped into a rotating drum and PCE is poured to the drum mixed with minimum water so as to getting a complete surface coating for RCA and to form a film of 0.1 to 0.3mm, throughout the surface.

From several trials, it is seen that 1 to 1.2% of PCE to the weight of RCA getting the good results (Kim et al, 2005 &Jiusu et al. 2009).
Figure 4. (a), (b), (c), (d), Reaction mechanism of surface coated RCA

Figure 4 shows the reaction mechanism of surface coated RCA, where (a) is the naked RCA and after coating, a film was formed on the surface of RCA as shown in (b). For making concrete, the surface coated RCA, mixed with cement, water, etc, and it is shown in (c) and RCA’s water absorption was restrained by the film that had been formed on the surface of the RCA. After the reaction of PCE on the surface of RCA, C-S-H hydrate was formed around the aggregate as shown in (d). The excess water absorption during mixing of concrete was reduced due to the surface coating.

D. Test for workability

The properties of RCA and coated RCA were investigated according to ASTM tests, with different ratio of RCA with NCA and coated RCA with NCA as 0%, 25%, 50%, 75%, 100%. The tests for Water cement ratio, Sand to aggregate ratio, Slump test for workability, and Compressive strength, were targeted as 0.5, 0.45, 150mm, and 24 N/mm², respectively.

By analyzing the results of fresh concrete, shown in Table 6& 7, the concrete mixture with RCA 25% requires about 5% more water quantity in comparison to mixture with RCA 0%, and the corresponding values for concrete mixture with RCA 50%, RCA 75% and RCA 100% are 9%, 13% and 16.5% respectively. Bulk density of concrete depends on aggregate type and quantity. The highest bulk density has concrete with natural aggregate (RCA or Coated RCA 0%) or control mix, and the lowest concrete with maximum content of RCA 100%. The bulk density decrease is about 3%. Whereas, the bulk density of concrete using surface coated RCA has increased considerably. The maximum increase was 1.5%.

E. Compression test:

Compressive strength of concrete can be defined as the measured maximum resistance of a concrete to axial loading. Compression test is the most common test used to test the
hardened concrete specimens with different percentage of recycled aggregate replacement can be indicating through the compression test. To evaluate the compressive strength properties, three specimens each of NCA, RCA and coated RCA were prepared according to ASTM C 192, 150mm x 150mm x 150mm specimens were used when the compressive strength was measured according to ASTM C 39 at 7th day and 28th day.

5. TEST RESULTS

The results of the test conducted on concrete using surface coated recycled coarse aggregate for its compressive strength, slump & air content losses, and reduction in water absorption, were obtained.

Table 7. Compressive strength of concrete- a comparison

<table>
<thead>
<tr>
<th>Grade of Concrete</th>
<th>% of recycled aggregate</th>
<th>Compressive strength at 7 days (N/mm²)</th>
<th>Compressive strength at 28 days (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RCA</td>
<td>Surface coated RCA</td>
<td>RCA</td>
</tr>
<tr>
<td>M20</td>
<td>0%</td>
<td>18.7</td>
<td>27.4</td>
</tr>
<tr>
<td>M20</td>
<td>25%</td>
<td>14.9</td>
<td>22.1</td>
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<td>M20</td>
<td>50%</td>
<td>13.8</td>
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<td>M20</td>
<td>75%</td>
<td>12.9</td>
<td>18.6</td>
</tr>
<tr>
<td>M20</td>
<td>100%</td>
<td>11.7</td>
<td>17.2</td>
</tr>
</tbody>
</table>

A. Compressive test
The compressive strength of all the samples are shown in Table 4. It shows that, the compressive strength by comparison, the strength of RCA with 25% is just attaining at 7th day. The rest of the results are not satisfactory. But in the case of PCE coated RCA, it shows a very successful result for 25%, 50% and 75% proportions. The sample with 100% coated RCA, the result just touched the limit.

6. CONCLUSIONS

The major deficiency of concrete using recycled course aggregate was its exorbitant percentage of water absorption compared to the natural course aggregate, and in this study, the following conclusions were drawn, 1. Surface coating with a super plasticizer (Polycarboxylate Ether) has been established that, excess water absorption due to the attached cement paste of RCA can control and the concrete using coated RCA upto 75% replacement can be used for all concrete works, except in the case of special purpose works like Prestressed, concrete, etc. 2. Test results shows that concrete using recycled course aggregate upto a replacement of 25% is safe for the general concrete works except in the case of structural works.

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