Properties of Concrete Made With Recycled Coarse Aggregate

Abstract

Using waste materials for new products is a growing global trend. In the construction field, this trend has gained importance because of natural aggregate depletion and landfill space depletion. This paper gives results of studies undertaken to assess suitability of construction demolition waste as coarse aggregate in new concrete production. In this paper the difference in properties of recycled aggregate (RA) and evaluating the influence of the RAs on the mechanical and durability properties of recycled aggregate concrete (RAC) are presented. While experimenting with fresh and hardened concrete, mixtures containing RA in amount of 25%, 50%, 75% and 100% were prepared. The experimental results showed that the RAC can be designed to achieve comparable hardened properties, relative to the corresponding properties of natural aggregate concrete (NAC).

1. Introduction

Concrete is a composite material, basically consisting of different constituents such as binding materials, water, aggregates and admixtures. Among these ingredients, aggregate plays a very crucial role in concrete which occupy the largest volume of about 60–75% of total concrete volume.
It is indispensable for any construction work (Behera et al. 2014). In recent years, the accelerating urbanization has led to excessive demolition work and construction activities, which consequently, resulted in the production of large quantities of construction and demolition (C&D) waste, especially concrete waste. More than 10 billion tons of construction and demolition waste are produced every year (Mehta 2002). In most cases, this type of waste is incorrectly managed through illegal deposits causing landfill space depletion. The main problems that industry of construction materials faces are: natural aggregate depletion, large amount of generated construction and demolition (C&D) waste and land fill space depletion. Recycling of waste concrete and producing recycled coarse aggregate (RCA), not only saves landfill space but also reduces the demand for extraction of natural raw materials for new construction activity (Radonjanin et al. 2013).

Reuse of recycled aggregate (RA) to fully or partially substitute natural aggregate (NA) has been extensively studied (Limbachiya et al. 2000, Sagoe et. al. 2001, Topcu and Sengel 2004, Zega and Di Maio 2011, and Duan and Poon 2014). From these studies it is worth noting that the properties of RA are generally poorer compared with those of NA, which are reflected in higher water absorption, porosity, aggregate crushing value (ACV), aggregate impact value (AIV) and Los Angeles abrasion value (LA), and lower specific gravity and 10% fines value (TFV). Limbachiya et al. (2000) found that recycled concrete aggregate had 7 to 9% lower relative density and 2 times higher water absorption than natural aggregate. Sagoe et al. (2001), Topcu and Sengel (2004), and Zega and Di Maio (2011) found that RA drastically lowers the workability of recycled aggregate concrete (RAC). Literature reports conforms that RAC suffers lower strengths, lower modulus of elasticity, and significant reductions in the energy of fracture and consequently on the fracture zone size, compared with natural aggregate concrete (NAC). The use of RA in practical application is generally limited to non-structural concrete, and the replacement ratio of NA by RA is recommended not to exceed 30% (Limbachiya et al. 2000, Topcu and Sengel 2004).

2. Experimental Program

2.1 Materials

Ordinary Portland cement of 53 grade conforming to IS 8112-1989 was used throughout the present work. As the present study aims to predict the effect of the RA on the performance of RAC, only conventional fine aggregate (locally available crushed sand) is used. Both NA and RA were used as the coarse aggregate in this study. Crushed gravel obtained from local quarry was used as NA. RA was obtained from an old demolished building. The nominal size of the natural and recycled coarse aggregates was 10 and 20 mm. The properties of NA and RA were determined in accordance with IS 2386-1963 and presented in Table 1. Superplasticizer conforming to IS 9103-1999 was used in this study.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Properties</th>
<th>Size (mm)</th>
<th>Aggregate type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>NA</td>
<td>RA1</td>
</tr>
<tr>
<td>1</td>
<td>Specific gravity</td>
<td>4.75-10</td>
<td>2.76</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10-20</td>
<td>2.76</td>
</tr>
<tr>
<td>2</td>
<td>Water absorption (%)</td>
<td>4.75-10</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10-20</td>
<td>2.77</td>
</tr>
<tr>
<td>3</td>
<td>Crushing value (%)</td>
<td>10-12.5</td>
<td>22.81</td>
</tr>
<tr>
<td>4</td>
<td>Impact value (%)</td>
<td>10-12.5</td>
<td>12.98</td>
</tr>
</tbody>
</table>
2.2 Concrete mixes and specimens preparation
Mix proportioning was done for M-40 grade concrete with target strength of 48 MPA at 28 days as per IS 10262-2009. A control mix (NAC) was prepared with 100% NA while RAC were made with 25, 50, 75 and 100% RA. The details of these concrete mixes are given in Table 2. All the concrete mixes were designed using absolute volume method with aggregates at saturated surface-dried (SSD) condition and the actual proportions of the mixes at mixing were adjusted according to the moisture contents and water absorption capacity of the aggregates. A total of five mixes of concrete were prepared. For each concrete mix thirteen 150 mm cubes and three 150 mm diameter, 300 mm height were cast. All the test specimens were cured in water curing tank until the age of testing. The compressive strength was determined at age 3, 7, and 28 days as per IS 516-1959. Splitting tensile strength (IS 5816-1999), water permeability test (DIN 1048), and rapid chloride penetration test (ASTM C-1202) was conducted at age 28 days.

<table>
<thead>
<tr>
<th>Mix series</th>
<th>Cement (kg/m³)</th>
<th>Sand (kg/m³)</th>
<th>NA 10 mm</th>
<th>NA 20 mm</th>
<th>RA 10 mm</th>
<th>RA 20 mm</th>
<th>Water (kg/m³)</th>
<th>Admixture (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA</td>
<td>450</td>
<td>795</td>
<td>484</td>
<td>592</td>
<td>-</td>
<td>-</td>
<td>165</td>
<td>4.95</td>
</tr>
<tr>
<td>RA 25%</td>
<td>450</td>
<td>795</td>
<td>363</td>
<td>444</td>
<td>101</td>
<td>131</td>
<td>165</td>
<td>4.95</td>
</tr>
<tr>
<td>RA 50%</td>
<td>450</td>
<td>795</td>
<td>242</td>
<td>296</td>
<td>202</td>
<td>262</td>
<td>165</td>
<td>4.95</td>
</tr>
<tr>
<td>RA 75%</td>
<td>450</td>
<td>795</td>
<td>121</td>
<td>148</td>
<td>303</td>
<td>393</td>
<td>165</td>
<td>4.95</td>
</tr>
<tr>
<td>RA 100%</td>
<td>450</td>
<td>795</td>
<td>-</td>
<td>-</td>
<td>404</td>
<td>524</td>
<td>165</td>
<td>4.95</td>
</tr>
</tbody>
</table>

3. Results and discussion

3.1 Properties of aggregate
The physical and mechanical properties of the investigated aggregates are shown in Table 1. Compared with NA, the RAs had a lower specific gravity and higher water absorption. This is attributable to the old mortar adhered to the recycled aggregate. The aggregate crushing value and aggregate impact value of RAs were also lower than NA due to separation and crushing of old mortar adhered to it (Duan and Poon 2014).

3.2 Properties of concrete
3.2.1 Workability
The workability of fresh concrete mixes was determined by slump test and the results are shown in Fig.1. The results showed that the workability of the concretes was gradually decreasing when the percentage of RAs increased. The reason is that...
the presence of porous adhered mortar in the RA increases water absorption, thereby reducing the workability of the fresh mix.

3.2.2 Compressive strength

The compressive strength of concrete made with NA and RA for the different replacement percentages are shown in Fig. 2. Each of the reported values represents the average of three values.

The general trend observed for 3- and 7-day strength is similar: the strength increases with increasing RCA content. This phenomenon may be because the free water content required for cement hydration was partially absorbed by RCA because of its absorptive nature. Consequently, there was a reduction in the effective W/C ratio. With the reduction in the effective W/C ratio, the mortar strength of RCA concrete was likely superior to that of the control mixes. Unlike the 3-day and 7-day strength test results, the 28-day compressive strength of RCA concrete did not show an upward trend with the increase in RCA content. A reduction in strength was observed when the RCA replacement level was more than 50%. The 28 days compressive strength of 100% RA was only 89% of NAC. In summary, the compressive strength of all the concrete mixes with up to 50% RCA replacement level showed higher strength than that of the control mix.

These trends can be attributed to two factors: effective W/C ratio and ITZ. Analogously, there was a reduction in the effective W/C ratio of RCA concrete because of its absorptive nature. In general, the higher the replacement level, the lower the effective W/C ratio. However, there is only one ITZ for the control mix, whereas RCA concrete has two ITZs, i.e., the interface between NCA and adhesion mortar (old ITZ) and the interface between the adhesion mortar and new mortar (new ITZ). Hence, the adhered mortar may play an important role in determining the performance of RCA concrete, particularly with respect to strength and permeability (Ryu 2002; Otsuki et al. 2003). Neville (1995) also noted that the influence of the type of coarse aggregate on the strength of concrete varies in magnitude and depends on the W/C ratio of the mix. For a W/C ratio below 0.4, the strength of the concrete is manipulated by the properties of the aggregate rather than the strength of the mortar. With an increase in the W/C ratio, the influence of aggregate declines, presumably because the strength of mortar itself becomes paramount. As the strength of the mortar...
depends considerably on the mortar class, a lower effective W/C ratio will produce higher mortar strength and, consequently, the strength properties of concrete will be enhanced.

### 3.2.3 Splitting tensile strength

The splitting tensile strength of conventional and recycled aggregate concrete are shown in Fig. 3. The result indicates that the concrete made with RA had splitting tensile strength similar to that of the corresponding natural aggregate concrete. This can be attributed to the rough surface of the RA that might improve the microstructure of the interfacial transition zone (Duan and Poon 2014).

![Figure 3: Tensile strength of various concrete mixes](image)

<table>
<thead>
<tr>
<th></th>
<th>NA</th>
<th>RA 25%</th>
<th>RA 50%</th>
<th>RA 75%</th>
<th>RA 100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength (MPa)</td>
<td>2.93</td>
<td>3.34</td>
<td>2.90</td>
<td>2.88</td>
<td>2.84</td>
</tr>
</tbody>
</table>

### 3.2.4 Water penetration test under pressure

The effect of different replacement percentages on the depth of water penetration under pressure are shown in Fig. 4. The results show that the average values of water penetration of recycled concretes are similar to, and in some cases better than those of conventional concrete. This can be attributed to an improvement in the transition zone of mortar-recycled aggregate (Zega and Di Maio 2011).

![Figure 4: Depths of water penetration for various concrete mixes](image)

<table>
<thead>
<tr>
<th></th>
<th>NA</th>
<th>RA 25%</th>
<th>RA 50%</th>
<th>RA 75%</th>
<th>RA 100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of water penetration (mm)</td>
<td>11</td>
<td>9</td>
<td>11</td>
<td>10</td>
<td>9</td>
</tr>
</tbody>
</table>

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### 3.2.5 Rapid Chloride penetration test

Figure 5 shows the effect of different replacement percentages on the resistance of chloride ion penetration of the concrete. The results show that all concrete made with recycled aggregates generally had better resistance to chloride ion penetrability, and it decreased as the percentage of recycled aggregate increased.

![Chloride ion penetration values for various concrete mixes](image)

<table>
<thead>
<tr>
<th>Total Charge Passed (Coulombs)</th>
<th>NA</th>
<th>RA 25%</th>
<th>RA 50%</th>
<th>RA 75%</th>
<th>RA 100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coulombs</td>
<td>5524</td>
<td>3836</td>
<td>3856</td>
<td>4165</td>
<td>4430</td>
</tr>
</tbody>
</table>

Figure 5: Chloride ion penetration values for various concrete mixes

### 4. Conclusion

The following conclusions can be made based on the results of this study:

I. Quality of recycled concrete aggregate is lower than natural aggregate quality, due to the mortar that remains attached on the surface.

II. The workability of the concrete was gradually decreasing as the amount of replacement of RA increased.

III. The compressive strength of the concrete mixes with up to 50% RA replacement level showed higher strength than that of the control mix. But when the percentage of recycled aggregate used increased, the compressive strength was reducing.

IV. For 100% replacement the compressive strength of recycled aggregate concrete was 11% lower than natural aggregate concrete.

V. Despite the increase in the RCA replacement level, the splitting tensile strength, water penetration and chloride penetration of the various concrete mixes did not show any significant difference.

VI. Hence, this study recommends the recycling of waste concrete as an aggregate material in production of new concrete.

VII. In conclusion, recycling coarse aggregates in concrete production may help solve a vital environmental issue apart from being a solution to the problem of shortage of natural aggregate in concrete.
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References


