Recycled Concrete Aggregate from C&D Wastes

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Abstract: The requirement of concrete aggregate in India is large. Corresponding to current annual production of cement of 300 million tonnes, total requirement of coarse and fine aggregate for use in cement concrete, mortars and plasters of about 1500 MT per annum is a safe estimate. Only aggregate from natural sources are allowed in Specifications. Of late, there is difficulty in obtaining natural aggregates for constructions within economic distances. This is due to environmental regulations which do not permit mining of rocks or dredging of sand from river beds. Search for alternate sources of aggregates thus assumes importance.

One such alternative is recycled concrete aggregate (RCA) derived from construction and demolition (C&D) wastes, which allow conservation of natural resources and land; prevent environmental pollution; and reduce the overall cost of construction. This paper discusses the use of recycled aggregate in structural concrete for new constructions, as is practiced in many countries. Techniques of processing C&D wastes, effects of RCA on the properties of concrete and international status of standardisation are described. Recent R&D work on use of RCA and fine fractions as replacement of coarse and fine aggregate in high strength concrete is described. This includes novel mixing techniques of virgin and recycled aggregate in concrete mixer. Proposed revisions of IS: 383 are mentioned.

The versatility of concrete as a material of construction is due to the fact that it is mostly made from naturally occurring materials and industrial wastes. Cement is made from naturally occurring raw materials and fuels; mixed with locally available aggregate and water to make concrete so will say the textbooks. Yet, in the contemporary construction scene in India, aggregate – coarse and fine – from natural sources are not available, neither water suitable for mixing and curing concrete from municipal supply sources. The situation has forced us to explore aggregate from alternate sources, and use of ground water or waste water after treatment.

One such alternate source for aggregate is the waste materials derived from demolition of old constructions and specification of new constructions. Aggregate in concrete constructions typically account for 75 percent of the total volume. The majority of concrete constructions till date essentially resort to aggregate materials derived from natural resources e.g. conforming to IS: 383. However, due to the need of conserving natural resources and issues relating to sustainability, environmental considerations and economy, increasing use of recycled and secondary aggregate has been forecast. Indeed, there are countries where construction materials are being increasingly judged by their ecological characteristics and the proportion of recycled aggregate used in concrete constructions at present is substantial. Concrete recycling gains importance because it protects natural resources and eliminates the need for disposal by using the readily available concrete as an aggregate source for new concrete or other applications.

Major part of C&D wastes originates from demolition of old constructions. These include variety of solid materials like excavated material, bricks, masonry, concrete, wood, metals and plastic etc. New constructions also give rise to wastes in smaller volumes; so are the leftover concrete from ready mix concrete plants, precast concrete plants, and shotcrete operations. Secondary aggregate, which originate from recycling of demolition wastes of asphalt constructions find use in the Roads sector. The present discussion focuses on use of recycled concrete aggregate in new concrete constructions, which are obtained mainly from processing of concrete remaining waste including concrete, masonry and asphalt). Status of standardisation and regulations in different countries, which guide such uses of recycled concrete aggregate, are reviewed. Recommendations for Indian Standards are made.

Definitions

In the present discussion, the following definitions will be adopted:

(a) RCA: Recycled concrete aggregate. (predominantly from demolition waste concrete).
(b) RA: Recycled aggregate. (predominantly from demolition waste including concrete, masonry and asphalt).
(c) LCAGg: Leftover concrete aggregate. (Aggregate processed from hardened leftover concrete of known composition that has not been in use and has not been contaminated in storage; typically from RMC plants, precast concrete plants, rebound from shotcrete applications etc.).

Volume and Composition of C&D Wastes

In Germany, C&D wastes amount to nearly 61 percent of MSW [1]. In some Asian countries, the proportion goes up to 42 percent [2]. Two Reports by Government agencies have stated that C&D wastes in India amount to nearly one-third of the total MSW [3, 4]. On that basis, the amount of C&D wastes can be estimated to be nearly 70 million tonnes per year,
CONCRETE RECYCLING

The objective of processing concrete rubbles will be to remove as much of adhered cement mortar as possible. This is achieved by crushing, scrubbing, heating or any other method adopted [11]. One criterion of separation could be that density of processed material is 2.5 gm/cc and water absorption restricted to 5 percent.

Table 1: C&D Wastes in Various Countries (Million Tonnes)

<table>
<thead>
<tr>
<th>Country</th>
<th>Amount, per year</th>
<th>Year</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>223</td>
<td>2003</td>
<td>1</td>
</tr>
<tr>
<td>Australia</td>
<td>19</td>
<td>2008-09</td>
<td>5</td>
</tr>
<tr>
<td>China</td>
<td>200</td>
<td>2005</td>
<td>6</td>
</tr>
<tr>
<td>Japan</td>
<td>85</td>
<td>2000</td>
<td>6</td>
</tr>
<tr>
<td>South Korea</td>
<td>61.7</td>
<td>2013</td>
<td>8</td>
</tr>
<tr>
<td>Ireland</td>
<td>11</td>
<td>2004</td>
<td>9</td>
</tr>
<tr>
<td>Norway</td>
<td>1.5</td>
<td>2003</td>
<td>10</td>
</tr>
<tr>
<td>India</td>
<td>14.7</td>
<td>2001</td>
<td>6 (Quoting MoEF)</td>
</tr>
<tr>
<td></td>
<td>10 – 12</td>
<td>2012</td>
<td>3.4</td>
</tr>
</tbody>
</table>

The first step towards recycling is use of excavators along with task-specific attachments to methodically dismantle buildings and to process the material at the site. Jaw crushers, jack hammers, saws, debris buckets, metal shears etc are widely adopted. Precast concrete elements and concrete blocks can be reused with little or no processing, if care is taken during demolition to separate them.

On-line and in-plant sorting and processing of C&D wastes are accomplished by use of both mobile and stationary machines. These include:
- Manual sorting lines
- Shredders
- Crushers
- Aggregate sifters
- Separators – water-based density separators, magnetic separators, eddy current separators, air blower separators etc.

Characteristics of Recycled Concrete Aggregate

In most cases, data on the original aggregate or concrete mix proportions, which are used in the constructions that led to the waste, may not be available. The strength characteristics of hardened concrete made with such aggregate are similar to those of natural rock and are not significantly affected by the grade or quality of the original concrete [12]. Recycled concrete aggregates produced from all but the poorest quality original concrete can be expected to pass the same tests required of conventional aggregates [12, 13].

The most significant factor is that recycled concrete aggregate contain not only the original aggregate, but also hydrated cement paste. This paste reduces the specific gravity and increases the porosity compared to similar virgin aggregates. Higher porosity of RCA leads to a higher absorption. Recycled aggregate will typically have higher absorption (see Figure 1) and lower specific gravity than natural aggregate; only lightweight aggregate may have higher water absorption [13].

Virgin aggregate from natural sources have specific gravity of 2.65 or more. Depending upon the amount of cement mortar adhering to it, which has lower specific gravity, the net specific gravity of RCA will be lower. The adherent mortar will absorb water, thereby again increasing water absorption. As will be elaborated later on, recycled concrete aggregate (RCA)
is characterised in specifications by its density and water absorption, among other characteristics (5).

Another property is alkali aggregate reactivity. Recycled concrete aggregate, which have been sourced from a number of demolition concretes, is likely to be alkali-reactive. The alkali content in the adherent mortar is also likely to contribute to potential activity. Many specifications, therefore, suggest tests for ASR activity to be carried out.

Recycled concrete aggregate, which have been sourced from a number of demolition concretes, are likely to exhibit greater variability than those sourced from one demolition concrete, and would affect the uniformity of resultant concrete.

Influence of RCA on Properties of Concrete

The main influence is on the strength characteristics of concrete made with RCA, which is generally lower than that made with virgin aggregate. The reason for the loss of strength is usually associated with [12];

- The weaker interfacial transition zone (ITZ) between the aggregate phase and the mortar, due to the aggregate already having a coat of weak mortar attached on its surface, and
- This attached mortar raising the porosity of the resultant concrete.

In an exhaustive review of published results, Dhir and Paine [12] have summarised the following trends on use of RCA as part or full replacement of virgin aggregate;

- Losses in compressive strength up to 15 percent for the same water-cement ratio. However, up to 20 percent (as in BS 8500-2) to 30 percent replacement of natural coarse aggregate by RCA can be made, without any significant influence on performance of concrete [3]. RCA were most effective in lower strength concretes.
- Fine fractions of RCA are not encouraged as replacement of fine aggregate (sand). However, it is used in many countries [5].
- Flexural strength and modulus of elasticity of RCA concrete are proportional to compressive strength. Typical relationships as given in design codes are compatible with the use of RCA.
- Drying shrinkage and creep of RCA concrete may be higher than in natural aggregate concrete. However, the values seldom fall outside the limit permitted in structural codes, and up to 20 replacements can give comparable results as in natural aggregate concrete.
- RCA concrete tends to be less resistant to those deleterious reactions which are dependent on fluid transport into concrete, mainly as a result of increased permeability. Chloride ingress is more rapid. Abrasion resistance is lower.
- RCA concrete has, however, better resistance to carbonation than natural aggregate concrete.

Portland Cement Association, USA States

'It is generally accepted that when natural sand is used, up to 30% of natural crushed coarse aggregate can be replaced with coarse recycled aggregate without significantly affecting any of the mechanical properties of the concrete. As replacement amounts increase drying shrinkage and creep will increase and tensile strength and modulus of elasticity will decrease, however compressive strength and freeze-thaw resistance are not significantly affected' [13].

Construction practices - It is generally recommended that RCA be batched in a pre-wetted and close to a ‘saturated surface dry’ (SSD) condition, like lightweight aggregates. To achieve the same workability, slump, and water-cement ratio as in conventional concrete, the paste content or amount of water reducer generally have to be increased [13]. Concrete with RCA can be transported, placed, and compacted in the same manner as conventional concrete. Special care is necessary when using fine RCA. Only up to 10% to 20% fine RCA is beneficial. The aggregate should be tested at several substitution rates to determine the optimal rate.

Use in High Strength Concrete - R&D in India

RCA as Replacement of Coarse Aggregate

In this study, the C&D waste were collected in boulder form, from demolished concrete pavements and other structures [14]. The collected material was crushed by hammer crusher, followed by jaw crusher, and finally by screening. Figures 2 (a) and (b) show typical C&D waste and recycled concrete aggregate obtained there from.

Figure 2: (a). Demolition Waste before Processing
The recycled aggregate (RCA) from the crushing plant was further processed in a Los Angeles abrasion test machine by using steel balls and rotated a total number of 700 revolutions @ 33 rpm for each batch of total weight 10 kg (two sizes of 20-10 mm and 10-5 mm each 5 kg). Such processed material (called PRA in this paper), was discharged from the machine and washed manually with water properly, till the water after washing was clean. The washed material was air dried and stacked in the laboratory before use in the experimental programme. All the aggregates including PRA were used in saturated surface-dry condition.

The processing of recycled concrete comprised different number of revolutions in the LA test machine. The effect of number of revolutions on properties of concrete was examined first. Typical results of 28-days compressive strength of concrete with different proportions of recycled concrete aggregate, which were subjected to varying number of revolutions and normal mixing, are shown in Figure 3. It can be seen that the strength decreased with proportion of recycled aggregate (PRA) compared to with virgin aggregate (zero percent PRA). For any proportion of PRA, the strength improved with the number of revolutions on PRA.

Similar was the effect on slump; 140 mm slump in control concrete decreased to 40 mm in case of 100 percent unprocessed aggregate (zero revolutions), but gradually increased to 80 mm with the number of revolutions (Figure 4). The trend in tests for other properties, reported in details elsewhere (15) were similar, which improved with the number of revolutions during processing of RA. There was not much improvement between 500 and 700 revolutions; as such processing was standardised as 500 revolutions, and were adopted in subsequent tests as reported hereinafter. After 500 revolutions, the specific gravity of processed aggregate was 2.62 and water absorption 1.47 percent. These are improvements over 2.60 and 4.16 percent respectively for unprocessed RA. In large constructions, appropriate machinery will have to be used (11) in place of LA test machine used in the present investigation.

**Two-Stage Mixing**

In normal mixing method (NMA), all the ingredients are fed sequentially and mixed in one go. For further improvement in the properties of concrete with recycled concrete aggregate, two-stage mixing has been advocated (15). In the two-stage mixing method, all the materials including processed recycled aggregate PRA (except virgin recycled aggregate) were loaded in the pan mixer in the first stage, and then the virgin coarse aggregate, which need not require any treatment, was added in the second stage of mixing to complete the process. In case processed recycled aggregate comprised the full (100 percent), it was mixed in the second stage. The total mixing time was 180 seconds in normal mixing (NMA) and 300 seconds in two-stage mixing.

Concrete produced in two-stage mixing showed better strength and durability results than normal mixing approach (NMA), because the PRA (500RVS) was completely repaired in the second stage mixing by filling up the old cracks, pores, voids, cavities, gaps and fissures etc. By using two-stage mixing approaches, the replacement level of virgin coarse aggregate with PRA up to 60 percent is suggested for higher grades of concrete more than 75 MPa (15).

Even with 100% replacement of virgin coarse aggregate with PRA, the strength up to 70 MPa can be achieved. The durability characteristics, especially drying shrinkage, abrasion resistance, chloride ion penetration, and creep, which was not investigated, need careful consideration in high strength concrete applications (15).

**Use of Fine Fractions as Sand Replacement**

The concrete rubble has to be properly processed, including scrubbing to remove the adhered hydrated cement as much as possible (14). The fine fractions obtained during such processing has to be used. Some countries like Norway, South Korea, and Japan etc. allow use of recycled fine aggregate in new concrete constructions (11). Use of fin-
er fractions (<4.75 mm) of recycled concrete as part replacement of fine aggregate from natural sources was investigated [16]. The results have been published recently, as such, only salient findings are reported here. The final <4.75mm fraction obtained was brought into grading zone II conforming to IS 383-1970, by suitably mixing.

Properties of fine aggregate from natural sources and recycled concrete are shown in Table 3. The quality of recycled aggregate is judged in terms of materials content, density and water absorption [11]. In many specifications, the limits of specific gravity (minimum) and water absorption (maximum) are 2.2 and 5 percent (South Korea) or 2.2 and 7 percent (Japan) respectively. If similar specifications are adopted in India, the present sample of recycled fine aggregate will satisfy the same.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Material</th>
<th>Water Absorption</th>
<th>Specific Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Natural Sand</td>
<td>0.21</td>
<td>2.6</td>
</tr>
<tr>
<td>2</td>
<td>Recycled Aggregate</td>
<td>6.2</td>
<td>2.41</td>
</tr>
</tbody>
</table>

Table 3: Properties of Fine Aggregate

Two control concrete mixes viz. M30, M40 were designed using virgin aggregates. Further mixes were obtained by replacing the fine aggregate fraction with recycled aggregate in steps of 10 percent, up to 50 percent. No other changes were made.

Construction and demolition waste has porous structure and high water absorption which resulted in loss of workability at high percent replacements. The target slump of 75 mm was reduced to 65 mm (M30 grade) and 59 mm in M40 grade, when 50 percent of sand was replaced by recycled aggregate [16]. This lowering of workability can be offset by use of chemical admixtures and using the aggregate in saturated surface dry condition. It is to be noted that no chemical admixture was used in the present investigation.

Compressive strength of concrete mixes for M30 and M40 grades up to 90 days are shown in Figures 6 and 7 respectively. From the results, it was found that the strength of the concrete mixes were continuously decreasing with the increase in replacement percentages of natural sand by construction and demolition waste.

The lowering of compressive strength was restricted to 11.3 percent for M30 grade and 7.1 percent in case of M40 grade at 28 days, when 20 percent of natural sand was replaced by recycled aggregate. For 10 percent replacement levels, the target strengths for M30 grade (38 MPa) and M40 grade (48 MPa) were achieved, without any adjustment in the water/cement ratio [16].

As in case of compressive strengths, the flexural strength tests on 100 x 100 x 500 mm beam specimens as per IS: 516 and split tensile strength on 150 x 300 mm cylinder specimens as per IS: 5816 for M30 and M40 grades up to ages of 90 days also decreased, as more and more of natural sand was replaced with recycled aggregate [16]. Typical results can be seen from Figures 7 and 8. The decrement in flexural strength was 5.9 percent at 28 days for M30 grade and 3.5 percent for M40 grade, when replacement level was 20 percent. These values are much more moderate than in case of compressive strength as discussed above.

Incorporation in Specifications

In order that a recycled material finds acceptance in the construction industry, comparison of its characteristics with those of traditional materials becomes necessary. Permission to use them incorporated in the national Codes and Specifications are also vital. Additional confidence building measures include ‘third party’ quality assurance schemes to test the characteristics of the recycled products and certify fitness for use.

Specifications for recycled concrete aggregate follow these steps;

- Specify chemical characteristics of recycled aggregate e.g. chloride content, influence on initial setting time of cement, water soluble sulphate and alkali content, to be at par with those of virgin aggregate,
- Decide the extent of removal of adherent cement mortar coating by density (dry or saturated) and water absorption. The extent of separation of the concrete rubble from soil, masonry etc. is judged by the constituents of the recycled aggregate.
CONCRETE RECYCLING

- Recycled aggregate are then classified into different categories, and
- Appropriate uses are recommended for each category in terms of exposure condition and strength requirements. Upper limit of replacement of natural aggregate with recycled material is specified.
- The specific provisions in different countries are discussed below;

European [CEN] Practice

EN 12620 was expanded to include recycled aggregate in the EN Standard for aggregate for concrete. According to it, the aggregate can be of the following types;
- Natural aggregates from mineral resources,
- Manufactured aggregates of mineral origin, involving thermal or other modification, and
- Recycled aggregate, resulting from processing of inorganic material previously used in construction.

UK - BS 8500-2:200628, which is the complementary British Standard to BS EN 206-1:200051, refers to two types of recycled aggregate (12);
- Recycled concrete aggregate [RCA], and Recycled aggregate [RA].

RCA is obtained from crushing demolished concrete structures, discarded precast elements and unused hardened concrete (12). In some modification of EN 12620, BS 8500 stipulates that RCA must be predominantly composed of concrete [at least 83.5 percent] and masonry content not more than 5 percent. Such aggregate can be used in structural concrete having cube strength of concrete 50 MPa. Recycled aggregate concrete containing crushed leftover concrete has no strength limitation provided the aggregate is not contaminated. For concrete cube strengths of 25 to 50 MPa, a maximum of 20 percent replacement of coarse aggregate applies, for designated concrete.

RA may contain masonry up to 100 percent. Because the potential composition of recycled aggregate [RA] is so wide, additional specification clauses may be required on a case by case basis. In particular, a project specification should include maximum acid soluble sulphate, method for determining the alkali content, ASR reactivity and any limitations on use in concrete. Recycled aggregate [RA] is limited to concrete cube strength of 20 MPa.

Provisions for the use of fine recycled concrete aggregate and fine recycled aggregate are not given in BS 8500-2:200628, but it does not preclude their use where it can be demonstrated, due to the source of material, that significant quantities of deleterious materials are not present. Fine recycled concrete aggregate should be assessed on a project specific basis.

BS 8500-2:200628 also places a restriction on the exposure classes in which recycled aggregate concrete can be located. Recycled aggregate concrete can be used for unreinforced concrete, internal concrete, and external concrete not exposed to chlorides or subject to de-icing salts, but is effectively excluded from sites with marine and other chloride exposure, from all but ‘moderate’ freeze thaw environments, and in aggressive soils. It also cannot be used in designated concrete for foundations or paving. However the recycled aggregate concrete can be used in such excluded zones if durability tests can demonstrate its suitability for the intended environment.

Because of lower proportion of masonry in RCA, its performance characteristics are regarded as better than those of RA. Consequently, there are fewer restrictions on their use in concrete subjected to different exposure conditions (12).

Germany –Germany has elaborated several regulations and indications determining standards for recycling materials in order to utilize them and make them an alternative to new materials. Most of them are used in road construction. Some guidelines for the use of recycled mineral materials in Germany are given in DIN 4226 – Aggregates for Concrete and DIN 4226-100 – Recycled aggregates for concrete and mortar.

DIN 1045 permits up to 25 percent RCA in structural concrete of cube strength 37.5 MPa in dry or low humidity environments. Challenges do however still exist and so long as virgin material prices are competitive recycled concrete will remain primarily dependant on the road construction market [1].

Norway – In a publication of 1999, it was reported that there were no specifications for recycled concrete aggregate. Proposal for such a specification was worked out and given in Table 4 below (17).

<table>
<thead>
<tr>
<th>Subject</th>
<th>Type I</th>
<th>Type II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral content</td>
<td>&gt;99 %</td>
<td>&gt;99 %</td>
</tr>
<tr>
<td>Concrete or rock</td>
<td>&gt;95 %</td>
<td>&gt;95 %</td>
</tr>
<tr>
<td>Concrete, rock, masonry or brick</td>
<td>1500</td>
<td>2000</td>
</tr>
<tr>
<td>Non-mineral content</td>
<td>1800</td>
<td>2100</td>
</tr>
<tr>
<td>(as wood, paper, metals, insulation materials, plastics, rubber, plant remnants and glass)</td>
<td>&lt;5 %</td>
<td>&lt;1 %</td>
</tr>
<tr>
<td>Density</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oven-dried, g/cm³</td>
<td>&gt;1000</td>
<td>&gt;1200</td>
</tr>
<tr>
<td>Saturated surface dry, g/cm³</td>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 4: (Ref. 17) Classification of Recycled Aggregate in Norway

Two types of aggregate are classified on the basis of mineral and non-mineral contents, density, and water absorption. Type II aggregate containing > 99 % concrete and rock is superior to Type I, which may contain more than 95 per cent of concrete, rock, masonry and brick. Limits of application are summarised in Table 5 below.

<table>
<thead>
<tr>
<th>Strength and exposure</th>
<th>Type I</th>
<th>Type II</th>
<th>Type I + II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine Aggregate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C25, mild</td>
<td>5 %</td>
<td>10 %</td>
<td>5 %</td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C25, mild</td>
<td>10 %</td>
<td>30 %</td>
<td>10 %</td>
</tr>
<tr>
<td>C55, moderate</td>
<td>0</td>
<td>20 %</td>
<td></td>
</tr>
</tbody>
</table>

Table 5: (Ref. 17) Allowed Proportion of Recycled Aggregate in Norway
CONCRETE RECYCLING

Fine aggregate from recycled concrete can be used up to 5 percent in case of Type I and 10 percent in case of Type II, for concrete of cylinder strength of 25 MPa (cube strength 30 MPa) and mild exposure – indoor structures in dry climate without aggressiveness.

Australia [5]

Standards Australia’s ‘Guide to the use of recycled concrete and masonry materials’ (HB 155:2002) defines two classes of recycled aggregate for use as aggregate for new concrete:

- Class 1A recycled concrete aggregate is predominantly recycled concrete.
- Class 1B recycled concrete aggregate can contain up to 30% brick content.

HB 155:2002 also defines two classes of recycled aggregate concretes [RAC’s]:

- Grade 1 recycled aggregate concrete is defined as concrete with up to 30% substitution level of Class 1A recycled concrete coarse aggregate. Grade 1 recycled aggregate concrete has a maximum specified strength limit of 40 MPa.
- Grade 2 recycled aggregate concrete is allowed up to 100% substitution level of Class 1A or Class 1B recycled concrete coarse aggregate. Grade 2 recycled aggregate concrete has a maximum specified strength limit of 25 MPa. Neither grade is permitted to contain recycled fine aggregate.

USA

Regulatory issues vary from state to state and agency to agency. Major uses being in road sub bases, State Highway officials were first to come out with guidelines. In 2005, California wrote legislation making mandatory and accepting use of recycled aggregate into new concrete. Other uses are in RMC and asphalt pavement. For structural applications, ASTM C94/C94M-11b55 allows replacement of 20 to 25% by weight of coarse aggregate generally (in structural concrete of higher grades); and 100% coarse aggregate replacement by recycled coarse aggregate should be allowed for concrete cube strengths up to 25 MPa [5]. Recycled aggregate obtained from returned leftover concrete from RMC plants are recommended for use in structural concrete up to 50 percent of coarse aggregate replacement; up to 100% replacement of coarse aggregate only is allowed for all non-structural applications. Use of fine aggregate obtained from recycled concrete are not encouraged [13].

A summary of provisions in some countries discussed so far is given in Table 6 [5]. In addition, provisions in Asian countries like Korea and Japan are discussed below.

<table>
<thead>
<tr>
<th>Country / Organisation</th>
<th>Recycled Aggregate (Type/Name/ Classification)</th>
<th>Aggregate Genre</th>
<th>Maximum RCA Substitution (%)</th>
<th>Maximum Recycled Aggregate Concrete 28 Day Cylinder Strength</th>
<th>Other Restrictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Kingdom</td>
<td>RCA</td>
<td>RCA</td>
<td>NR</td>
<td>40 Mpa</td>
<td>RCA and LCAGG. No chloride exposure No freeze thaw</td>
</tr>
<tr>
<td></td>
<td>LCAGG</td>
<td>LCAGG</td>
<td>20%</td>
<td>Designated concrete 20 to 40 Mpa</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RA</td>
<td>RA</td>
<td>NR</td>
<td>NR</td>
<td>Only mild exposure</td>
</tr>
<tr>
<td>Australia</td>
<td>Class 1A</td>
<td>RCA</td>
<td>30%</td>
<td>40 Mpa</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Class 1B</td>
<td>RCA</td>
<td>100%</td>
<td>25 Mpa</td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>LCA</td>
<td>LCAGG</td>
<td>100%</td>
<td>20 Mpa</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>25%</td>
<td>50 Mpa</td>
<td>Masonry Aggregate. Ex</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>60%</td>
<td>NS Concrete</td>
<td></td>
</tr>
<tr>
<td>RILEM</td>
<td>RCAC Type I</td>
<td>RA</td>
<td>100%</td>
<td>16 Mpa</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RCAC Type II</td>
<td>RCA</td>
<td>100%</td>
<td>50 Mpa</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RCAC Type III</td>
<td>RCA</td>
<td>20%</td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>Korea</td>
<td>-</td>
<td>RCA</td>
<td>30%</td>
<td>27 Mpa</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>30%</td>
<td>21 Mpa</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>Type 1</td>
<td>RCA</td>
<td>35%</td>
<td>25 Mpa</td>
<td>In dry or low humidity environments</td>
</tr>
<tr>
<td></td>
<td>Type 2</td>
<td>RCA</td>
<td>25%</td>
<td>30 Mpa</td>
<td></td>
</tr>
<tr>
<td>Portugal</td>
<td>ARB1</td>
<td>RCA</td>
<td>25%</td>
<td>35 Mpa</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ARB2</td>
<td>RCA</td>
<td>20%</td>
<td>40 Mpa</td>
<td></td>
</tr>
<tr>
<td>Hong Kong</td>
<td>-</td>
<td>RCA</td>
<td>20%</td>
<td>&lt;35 Mpa</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>100%</td>
<td>20 MPa NS Concrete</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 6 [From Ref. 5] Summary of Provisions in some countries
Water absorption, %

Material passing 75µ, %

Scope of application

Properties

RA-L

RA-M

RA-H

Coarse

Fine

Coarse

Fine

Coarse

Fine

Oven-dry density, g/cm³

>2.5

>2.5

>2.3

>2.2

Water absorption, %

<3.0

<3.5

<5.0

<7.0

Material passing 75µ, %

<1.0

<7.0

<1.5

<7.0

Strength 45 MPa, no restriction of exposure

Members not subjected to drying or freezing and thawing

Backfill concrete, blinding concrete, levelling concrete

Table 7: [Ref. 7] Requirements for Recycled Aggregate in Japan

South Korea

Korean Standard KS F 2573 allows the use of recycled aggregate recovered from demolished concrete. The requirements for recycled aggregate are as under (8):

Coarse aggregate - oven-dry density > 2.5 g/cm³, water absorption <3 percent.

Fine aggregate - oven-dry density > 2.2 g/cm³, water absorption <5.0 percent.

Permitted grades of concrete using RCA are as under:

Strength class of 27 MPa and under – up to 30 percent replacement of only coarse aggregate.

Strength class of 21 MPa and under – up to 30 percent replacement of coarse aggregate and fine aggregate.

Japan

Standardisation of recycled aggregate in Japan has progressed in stages. In 1977, Building Contractors Society set up guidelines in terms of oven-dry density and water absorption of recycled aggregate. For coarse aggregate, the limiting values were > 2.2 g/cm³ and 7 percent respectively; for fine aggregate, the limits were > 2.0 g/cm³ and < 13 percent (7).

Subsequent revisions followed intensive research activities by many agencies and improvements in techniques of recycling, leading to formulation of three classes of recycled aggregate in 2007 by Japan Industrial Standards Committee. The details are given in Table 7 [7].

Recommendations for BIS Specifications in India

In so far as use in concrete is concerned, IS: 456, IS: 1343 or IRC: 112 do not permit use of aggregate other than those obtained from natural sources and conforming to IS: 383. In view of international developments and experiences, as well as shortage of aggregate from natural sources being experienced in many parts of the country, it is time that recycled aggregate are permitted for use in concrete constructions.

Recently, in March 2015, BIS has issued proposed revisions in IS: 383, which will allow use of coarse and fine aggregate derived from processing of recycled concrete as part replacement of natural sand (18). The amounts permitted, for both coarse and fine aggregate, are;

- 100 percent in lean concrete (up to M15 grade),
- 25 percent in plain concrete, and
- 20 percent in RCC (up to M20 grade).

These are welcome suggestions. Perhaps, BIS can raise the grade of concrete to M25 in case of RCC. At the same time, it is necessary to stipulate minimum density of 2.5 g/cc and maximum water absorption of 5 percent, for use in RCC. This will ensure that only processed recycled concrete aggregate are used.

References

4. Construction & demolition (C&D) waste; Collection, transportation and disposal system, Project Report for MCD, Delhi Solid Waste Management Program, 38p. Prepared by IL&FS ECOSMART.