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# Suitability of Recycled Concrete Aggregates as Construction Material in Construction Field: A Technical Review

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***Abstract:*** *A sustainable construction has become a great concern over construction practice at the expense of the future of our environment. Depletion of natural resources due to massive consumption by the construction industry and disposal of a huge amount of construction and demolition waste poses threat to environment and require large landfill site area, high transportation cost and loss of reusable & recyclable material. Therefore, utilizing recycled or reused concrete aggregates is beneficial for various applications in construction. It is a significant effort towards sustainable construction and an effective way to implement "green" concrete for new construction. Reusing the construction and demolition waste not only preserve the environment but also ensure effective utilization of resources and can reduce the project cost and leads to sustainable development. This study presents a review on the production of recycled concrete aggregate, engineering behavior, properties and durability of Recycled Concrete Aggregates (RCA) with its possible use in construction field.*

***Keywords:*** *Recycled concrete aggregate, sustainable construction, Compressive strength, Construction and Demolition waste*

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## I. Introduction

High consumption of raw materials in the construction to meet infrastructural demand causes damage to environment, pollution and depletion of natural resources. A huge amount of construction and demolition waste (non-usable and inert waste) is generated by the constructional activities. Disposing off such large amount of C&D waste is not desirable because of requirement of large landfill site area, high transportation cost and loss of reusable & recyclable material.A sustainable construction has become a great concern over construction practice at the expense of the future of our environment. This is due to the fact that the construction industry is massive consumer of natural resources and a huge waste producer as well. Therefore, utilizing recycled or reused concrete aggregates is beneficial for various applications in construction. It is a significant effort towards sustainable construction and an effective way to implement "green" concrete for new construction.

Recycled concrete aggregate (RCA) is generated during construction and demolition of a concrete structure which can be reused in place of natural aggregates (Tiwari, 2015). The properties of RCA are different from natural aggregates. The difference between RCA and natural aggregate is the adhered mortar at the surface of the RCA. It is a porous material, exhibit lower bulk density and saturated surface dry density (SSD). The bulk density of RCA is comparable to that of the lightweight aggregate (Serpa et al., 2013).

The concept of reusing/recycling waste concrete as RCA has been used since World War II in Europe as unbound sub-base or load-bearing layer material of the pavement because natural aggregates cannot be regenerated in a short period of time.General practice is to landfill or using the C&D waste for backfilling. However, there are a variety of benefits in recycling concrete rather than dumping it or burying it in a landfill.

- Keeping concrete debris out of landfills saves landfill space.
- Using recycled material as gravel reduces the need for gravel mining.
- Using recycled concrete as the base material for roadways reduces the pollution involved in trucking material.

## II. Production of RCA

RCA is a granular material manufactured by removing, crushing and processing concrete for reuse with a hydraulic cementing medium to produce fresh concrete (Donalson et al., 2011).

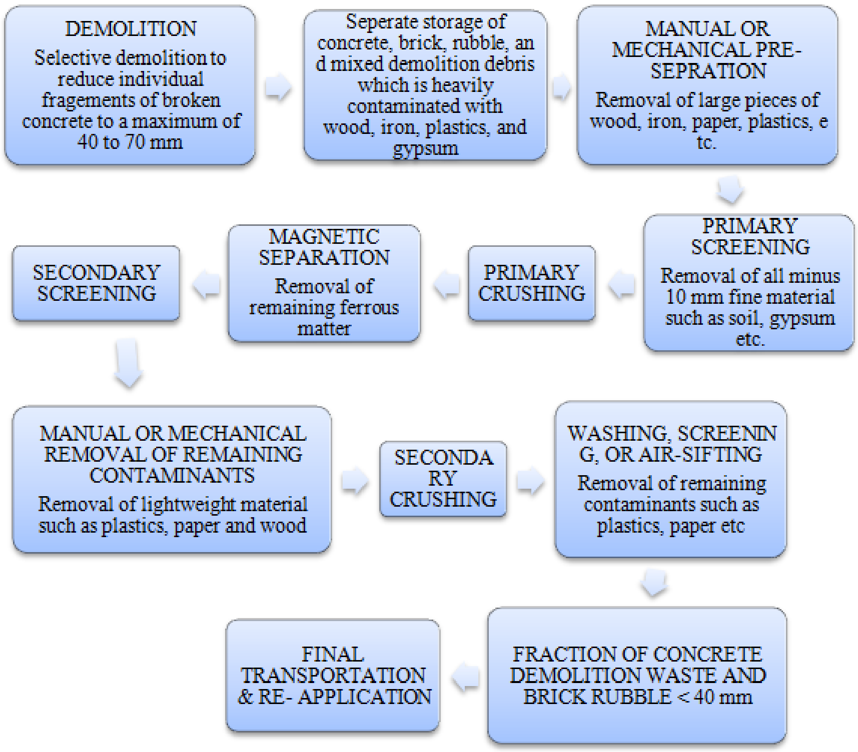


**Figure 1.**Typical Crushing Plant Process and Procedure for Concrete Aggregate

## 2.Technical Properties of Recycled Concrete Aggregates

**2.1.Compressive Strength:** There exists inverse relationship between RCA content of concrete and its compressive strength. This is due to poor quality and porosity of adhered mortar. Compressive strength of RCA depends on different factors like replacement percentage, water-cement ratio, moisture content of recycled aggregate etc. It has been reported by different investigations that upto 25-30% replacement, no significant reduction observed in compressive strength of RCA concrete. RCA replacement level up to 50% still achieved medium target strength .At 100% replacement, reduction in compressive strength is reported upto 30% as compared to natural aggregates.

**2.2.Low bulk and SSD density**: Adhered mortar at the surface of the RCA is a porous material, which contributes to low bulk density (1290-1470 kg/m$^3$) and saturated surface dry density (2310-2620 kg/m$^3$) of RCA, which is comparable to lightweight aggregates (Xuping Li, 2008).

**2.3.High Porosity:** the higher porosity of RCA is due to the higher content of adhered mortarresponsible for its low resistance towards mechanical and chemical actions. Relating the influence of RCA size on porosity it was found that with same replacement ratio, coarse RCA produces concrete mix with much less porosity than fine RCA.

**2.4. Modulus of Elasticity:** The effect on Modulus of elasticity by using RCA is more pronounced and it decreases with increase of RCA content, even when compressive strength of concrete mix with RCA is equivalent to that of conventional concrete, its modulus of elasticity is lower and therefore deformation in structures are greater**.** For elastic modulus, the reduction is about 45% when the coarse aggregate of concrete was completely replaced with the RCA.
**2.5.Water Absorption**: RCA absorbs water during mixing process due to reduced water content in adhered mortar at the surface of aggregate. Water absorption value is directly proportional to replacement content of RCA. As RCA content in concrete increases, water absorption increases and more water is often needed for concrete mixing. Absorption values of RCA containing concrete are greater than that of the normal concrete. Water absorption value is considered low(less than 3%) for both normal concrete and RCA concrete, when replacement content is less than 30%. RCA concrete with 80% replacement has high absorption capacity as shown in Fig. 2 (Kwan et al., 2011).
Water absorption, bulk density and specific gravity of RCA and natural aggregates are shown in table 1.
Table 1: Technical Properties of RCA and Natural Aggregates.

| Physical properties | Water absorption | Bulk density | Specific gravity |
|---|---|---|---|
| **NA** | 1.58 | 1470.8 | 2.65 |
| **RCA** | 6.6 | 1324.98 | 2.2 |

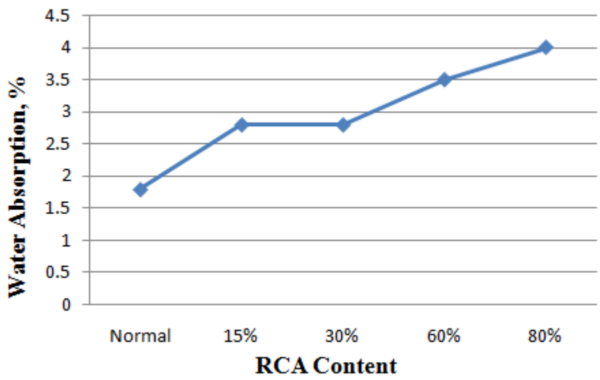


**Figure 2.** Water Absorption at Different RCA Content

**2.6.Tensile and Flexural Strength:**The reduction effect in the uniaxial tensile strength of RCA is up to about 30% In terms of the flexural strength, it has been reported that the RCA content has insignificant influence on that.

**2.7.Workability:** Required workability is difficult to obtain due to more slump loss and requirement of more water being porous in nature than natural aggregate concrete to maintain same workability. At high replacement level (greater than 50%), loss in workability of RCA concrete is found to be more prominent. The Slump loss of RCA concrete can be overcome by using admixtures or super plasticizersto maintain the desired workability (Behara et al, 2014).

## III. Applications of RCA

### 3.1. As Alternative Pipe Backfilling Materials

Based on different physical, geotechnical and chemical tests, RCA is found to be suitable alternative material as pipe backfilling material for storm-water and sewer pipes. This is more important in Indian context where lot of urbanization and infrastructure development is under progress which involves laying of storm water and sewer pipes. Pipe backfilling specifications by government authorities worldwide specify requirements related to different properties such as strength, grading, particle density and compaction. The properties of RCA were compared with local engineering and water authority specifications for typical quarried materials to assess performance of recycled material as a substitute for natural aggregates. The value of specific gravity, water absorption, organic content, pH, hydraulic conductivity, los- angeles abrasion value, MDD (maximum dry density), OMC (optimum moisture content) and shear strength were found to be in specified limits(Rahman et al., 2014).Instead of using C&D waste in backfilling for reclamation, using RCA for pipe backfilling is more value added and environment friendly practice as it will save quarrying of natural aggregates for less important backfilling works. Saved natural aggregates can be used in more value added structural concrete work.

### 3.2. As Mineral Addition in Cementitious Materials

Environmental issues have led European stakeholders to join around an ambitious project, the reuse of 70% of inert wastes from C&D by 2020.In France, cementitious materials represent more than a third of the 20 millions of tons of wastes generated per year by the construction industry (L. O.Nelfia et al., 2015).For this purpose among the various measures, one of the proposed measures is to use RCA as a mineral additive in form of Recycled Crushed Concrete Fines (RCCF). RCCF is formed after a process of crushing and sieving RCA. Although this approach of using RCCF as mineral additive requires additional process for transformation of the raw material, it presents several environmental benefits such as:

- It increases the recovery potential of RCA.
- RCCF was found to play a similar role than limestone filler on cement hydration. RCCF can be used as a substitute of usual addition of limestone filler that would reduce quarrying of natural resources and $CO_2$ emissions of concrete resulting from clinker.

- Mineral additions are more and more used for partial replacement of Portland cement which is known as most impacting constituent of concrete on the environment. Portland cement could be substituted by RCCF up to 25% without altering properties of mortar.

**3.3. RCA in Concrete-Filled Steel Tubes (RACFST)**

Confining concrete in steel tubes has long been recognized as an effective means to improve the behavior of concrete not only because confinement increases the compressive strength of concrete and helps suppress crack development, but the core concrete is sealed from moisture exchange with the surroundings and its lateral deformation is significantly restricted by the steel tubes (Chen et al., 2016). The bond strength between RCA and steel tube in general increases with an increase in recycled concrete aggregates replacement percentage, provided that the RCA used are not pre-soaked. Test on stub columns have shown that on the materials level, both strength and deformation of RCA improve due to the confinement of the concrete and strength contribution by the steel tubes. The cyclic behavior of RACFST members is quite comparable to those made from natural coarse aggregates. Tests carried out on RACFST frames have shown that they perform well under cyclic loads. An increase in RCA content does not have a noticeable effect on their performance.

**3.4. Generation of Eco- Friendly Concrete Blocks by Accelerated Mineral Carbonation**

Carbon dioxide ($CO_2$) Capture and storage is an important option in the portfolio of mitigation actions to reduce greenhouse gas emissions. In practice, there are many available alkaline waste that have potential of $CO_2$ capture and storage, such as steel slags, cement kiln dust, coal fly ash, municipal solid waste incineration ashes, RCA etc. Among all waste streams, Concrete waste accounts for the largest portion, it is also acknowledged that the production of cement contributes to more than 5% of total anthropogenic $CO_2$ emissions.

In recent years, accelerated mineral carbonation of concrete products has been proposed as a mean for reducing $CO_2$ emission. It is a process under $CO_2$ rich environment at certain pressure, which may facilitate rapid reactions between $CO_2$ and the cementitious components in a few hours. In terms of this technology, concrete products may rapidly attain the required strength with significantly enhanced resistance to surface permeation, sulphate attack and freeze-thaw cycle .When subjected to 2-h $CO_2$ curing , the strength of concrete blocks was similar to that of the water cured samples at 28 days . The carbonated RCA attained an increase in density and strength and decrease in water absorption (D.Xuan et al., 2016).

Adopting this production method for concrete blocks would improve the properties of concrete blocks as well as increase the reusing rate of RCA by 35%, may reduce the drying shrinkageand to some extent mitigate the industrial $CO_2$ greenhouse gas emission to the atmosphere.

**3.5.Non- Structural Use of RCA**

Due to its inherent propertiesRCA can be used to make porous paving that allows storm water to percolate into the ground which will help in ground water recharging in today's concrete jungles of urbanized India.RCA can also be used for making interlocking paver blocks and Kerb stones. The new MSW Rule'2016 for C&D waste disposal made it mandatory to use 10% of C&D waste in all Govt. Contracts. Interlocking paver block made from RCA is one of the best uses to comply with this regulation as paver blocks are extensively used in Govt. contacts of village roads and footpaths etc.

**3.6. RCA in Highway Construction as Base Material**

Recycled concrete aggregate (RCA) is most frequently used in highway construction as a base material, as backfill in granular embankment, in low performance asphalt or hydraulic cement concrete. For highway construction, processing the RCA to a high quality product is essential to uphold strength of material design standards.High quality RCA is even suitable forhigh performance asphalt or hydraulic cement concrete. Economics become more favorable towards RCA when transportation cost of natural aggregate is quit high or is not readily available.

## IV. Measures to increase use of RCA

1. Regulatory measures are very important to increase use of recycled concrete aggregate from C&D waste one such step is the new MSW Rule'2016 for C&D waste disposal made it mandatory to use 10% of C&D waste in all Govt. Contracts. Similarly Govt. should issue BIS code for Concrete structure with RCA. It should also be included in schedule of rates (SORs) of various works departments of Govt. Currently 10-20% RCA use in concrete is allowed in Singapore (K. C. Chew,2010).
2. Formation, Enactment andEnforcing Demolition Protocol, which is a set of procedures as how demolition waste should be managed to maximize resource recovery for beneficial reuse and recycling of concrete.
3. An accreditation scheme of C& D waste recyclers, which aims to improve quality consistency of Recycle concrete aggregate (RCA) production.

**4.** Tax on generation and landfill of C& D waste, the fund so generated may be used to establish RCA production plant and to subsidize its use.By imposing charges on C&D waste Hongkonghas reduced 60% landfill of C&D waste.

## Conclusion

Sustainability in construction can be achieved through conservation of resources & energy,reuse and recycling of C&D waste. Use of RCA will help natural management of C&D waste and replacement of natural aggregate.The engineering performance of RCA is somewhat inferior to conventional concrete, but RCA has been gaining wide attention as a construction material. Concrete has good tensile strength when replaced up to 25-30%. RCA replacement level up to 50% still achieved medium target strength. The water absorption value is directly proportional to the level of RCA replacement. RCA can be used for non- structural concrete works such as porous pavements, interlocking paver blocks, kerb stones etc. it can also be used for pipe backfilling material, as mineral additive in cementitious material, RACFST etc. Regulatory framework is required to increase use of RCA in concrete structures. This will lead towards more sustainable construction by proper management of C&D waste, conservation of natural resources and minimization of $CO_2$ emissions.

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