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An Introduction to Recycled Aggregate Concrete: Production and Applications

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ABSTRACT
To obtain good quality concrete using recycled aggregate it is necessary to follow the minimum requirements defined by the respective Building Standards. Acceptable properties of aggregates are an elemental base for concrete quality; however adequate mix proportions and concrete production methods are highly important in concrete quality too. Recycled aggregates composed of original aggregates and adhered mortar. The physical properties of recycled aggregates depend on both adhered mortar quality and the amount of adhered mortar. The adhered mortar is a porous material; its porosity depends upon the w/c ratio of the recycled concrete employed. When structures made of concrete are demolished or renovated, concrete recycling is an increasingly common method of utilizing the rubble. Concrete was once routinely trucked to landfills for disposal, but recycling has a number of benefits that have made it a more attractive option in this age of greater environmental awareness and the desire to keep construction costs down.

Keywords: concrete recycling; crushing process; recycled aggregate; sustainable concrete; durability; benefits and uses

1. INTRODUCTION

1.1. General Analysis

The concrete industry makes up approximately 30% of the total market for aggregates and it is estimated that 165 million tones are used annually in concrete. There is, therefore, considerable incentive to develop alternative aggregate sources based on waste materials. The aggregate products currently coming from most aggregate recycling plants are unbound fills, capping, sub-base and pipe bedding as the recycled concrete aggregate (RCA) or RAC is blended with other materials and is thus unsuitable for ready-mixed concrete. There have been some site trials with RCA supplied in ready-mixed concrete, but these were not mainstream options.

Trench arising, containing stone, concrete, brick, asphalt and clay, are produced by utilities companies, which can then be incorporated into a low strength concrete producing a cost effective trench fill material. Foamed concrete using the <4mm fines from RCA is also used in trench reinstatement and there is potential to use incinerator bottom ash aggregate in foamed concrete as well. The concrete standard BS 8500 has improved the potential for use of recycled aggregates in concrete as BS EN 12620, *Aggregates for concrete*. It is expected that there will be an increase in the use of recycled aggregates for concrete in the next few years, but currently it is not widely available.

1.2 Characteristics of Recycled Aggregate Concrete

Recycle aggregate concrete has a crushed sound and clean waste concrete of at least 95% by weight of concrete with typical total contamination lower than 1% of the bulk mass. Class 1A RCA is a well graded RCA with not more than 0.5% brick content.

The crushing characteristics of hardened concrete are similar to those of natural rock and are not significantly affected by the grade or quality of the original concrete. Recycled concrete aggregates produced from all but the poorest quality original concrete can be expected to pass the same tests which are being required for testing of conventional aggregates. Recycled concrete aggregates contain not only the original aggregates, 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.

1.3 Mix Design Procedure Using RCA

It is generally accepted that when natural sand is used, up to 30 percent 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.

It is recommended that RCA must be batched close to a saturated surface dry 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.

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 percent fine RCA is beneficial. The aggregate should be tested at several substitution rates. Often recycled aggregate is combined with virgin aggregate when used in new concrete.

1.4 Sustainability

Recycling concrete provides sustainability in several different ways. The simple act of recycling the concrete reduces the amount of material that must be land filled. The concrete itself becomes aggregate and any embedded metals can be removed and recycled as well. As space for landfills becomes premium, this not only helps reduce the need for landfills, but also reduces the economic impact of the project. Moreover, using recycled concrete aggregates reduces the need for virgin aggregates. This in turn reduces the environmental impact of the aggregate extraction process. By removing both the waste disposal and new material production needs, transportation requirements for the project are significantly reduced. In addition to the resource management aspect, recycled concrete aggregates absorb a large amount of carbon dioxide from the surrounding environment. The natural process of carbonation occurs in all concrete from the surface inward. In the process of crushing concrete to create recycled concrete aggregates, areas of the concrete that have not carbonated are exposed to atmospheric carbon dioxide.

The **LEED** Green Building Rating System recognizes recycled concrete in its point system. Credit 4 (Materials and Resources) states, "specify a minimum of 25 percent of building materials that contain in aggregate a minimum weighted average of 20 percent post-consumer recycled content material, OR, a minimum weighted average of 40 percent post-industrial recycled content material." Using recycled aggregates instead of extracted aggregates would qualify as post-consumer. Because concrete is an assembly, its recycled content should be calculated as a percentage of recycled material on a mass basis.

Credit can also be obtained for Construction Waste Management. It is awarded based on diverting at least 50 percent by mass of construction, demolition, and land clearing waste from landfill disposal. Concrete is a relatively heavy construction material and is frequently recycled into aggregate for road bases or construction fill.

1.5 Equipments Used in Recycling Concrete

Figure 1: Asphalt recycle grinding machine **Figure 2:** Grinding machine for concrete crusher

Figure 3: Aggregate crusher

Figure 4: Concrete recycling robot

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2.0 STRENGTH OF REINFORCED CONCRETE WITH RECYCLED COARSE AGGREGATE

Strength of reinforced concrete is defined as the maximum load or stress it can carry. Concrete is strong in compression but weak in tension. Because of this, concrete structures with exception of pavement are designed on the assumption that concrete carries little or no tension but carries compression, while reinforcements (steel) are designed to withstand tension.

With the rapid advancement of concrete technology, high strength concrete is being increasingly widely used in the construction of high-rise buildings and other reinforced concrete structures. However, the tensile and shear strength of high strength concrete do not increase in proportion with the compressive strength. And of the two strength properties, the shear strength is of particular importance because the tensile strength is not normally relied on for carrying load but shear is unavoidable in beam column framework. Although there has been a rapid growth of interest in high strength concrete, current specifications for the shear strength of reinforced concrete beams in the American concrete institute [ACI] Building code and British standard are based on results of beam tests done using concrete with relatively low compressive strength.

Compressive Strength of Concrete with RCA

The compressive strength of concrete is evaluated by the concrete's 28 days cube strength. BS requires that the specimen load per unit area sustained by a concrete specimen before it fails in compression. BS stipulates that the usual test is the crushing of a 150mm cube in a compression machine loaded at the rate of 15Nmm^{-2} without reinforcement. However, when the maximum size of aggregate does not exceed 19mm. 100mm cubes can be used for laboratory work. Most structural concrete are proportioned to have strength of 20-30Nmm^{-2}at 28 days.

Tavakoli M., Soroushian P. studied that concrete made with 100% of recycled coarse aggregate with lower w/c ratio than the conventional concrete can have larger compression strength. When the w/c ratio is the same the compression strength of concrete made with 100% of recycled aggregate is lower than that on conventional concrete. For the recycled aggregate concrete it will be necessary to add more cement in concrete made with 100% of recycled aggregate in order to achieve the same workability and compression strength as conventional concrete. Any variation in concrete production or in the properties of the constituents used produces a variation of strength in the resultant concrete.

Tensile Strength of Concrete with RCA

This is of great importance in the design of concrete roads, railways etc. Concrete members are also required to withstand tensile stresses resulting from restraint to contraction due to drying or temperature variation.

Unlike metals it is difficult to measure concrete strength in direct tension and indirect methods have been developed for assessing this property. The concrete strength in direct tension is evaluated by "split cylinder test". This method entails diametrically loading a concrete cylinder in compression along its entire length. The load induces tensile stress over the loaded diametrical plane and the cylinder splits along the loaded diameter. The magnitude of the induced tensile stress at failure in expressed as:

Fct = 2F/ (3.14xL.d)

Where; F = Applied load

L = Length of cylinder

d = Diameter of cylinder

Flexural Strength of Concrete with RCA

The flexural strength of concrete is known as the modulus of rupture that is used to evaluate tensile strength as determined from tests on beams. The standard size of beams for flexural tests according to (BS 1881) is 150mm x 150mm x 700mm. However, the American society for testing materials (A.S.T.M) stipulates that the length of the beam should be at least 50mm longer than three times its depth and its width should be not more than one and half times its depth. The minimum depth of width should be at least three times the maximum size of aggregate and not less than 50mm. This is determined from simply supported beam loaded at the three points. The resulting bending moment induces compressive and tensile stresses in the top and bottom of the beam respectively. The beam flexural strength is given as:

Fct = F.L/ (b.d.d)

Where; F = Applied load

L = Effective span

b and d = Breadth and depth of beam respectively.

The strength in bending is the extreme stress on the tensile side of a point at the point of failure. The ultimate strength of under reinforced beams in flexure is insensitive to the model used to represent the stress-strain relationship. It is only where failure occurs by crushing of concrete in compression that the different stress-strain relationship may result in different calculated ultimate strength.

2.1 Advantages of Recycled Aggregate Concrete

We all know that recycling materials is good for the environment otherwise it would end up in a landfill. This is particularly true when you are dealing with bulky materials that take away precious space for real garbage. By recycling aggregate like asphalt or concrete, we:

1. Reduce the amount of virgin rock mined: That means less mining, less blasting, and more of a precious resource is preserved for the coming generations.

2. Decrease the energy used for processing: Turning reclaimed material back into useable aggregate requires less energy than processing virgin stone.

3. Conserve the energy used for trucking: When we create recycled materials onsite, there's no trucking cost, environmentally and financially it is good.

4. Lessen the pollution and CO produced at each step of the process: The majority of recycling operations reduce the power and fuel consumption needed during production and distribution.

2.2 Process of Making Recycled Aggregate Concrete

Steps involved in recycled aggregate concrete:-

- Crushing
- Pre-sizing
- Sorting
- Screening
- Contaminant elimination

Production Sequence of RAC:-

1) Crushing and screening systems start with primary jaws, cones and/or large impactor taking rubble from 30 inches to 4 feet.
2) A secondary cone or impactor may or may not need to be run, and then primary and secondary screens may or may not be used, depending upon the project, the equipment used and the final product desired.
3) A scalping screen will remove dirt and foreign particles. A fine harp deck screen will remove fine material from coarse aggregate.

4) Further cleaning is necessary to ensure the recycled concrete product is free of dirt, clay, wood, plastic and organic materials.

5) This is done by water floatation, hand picking, air separators, and electromagnetic separators.

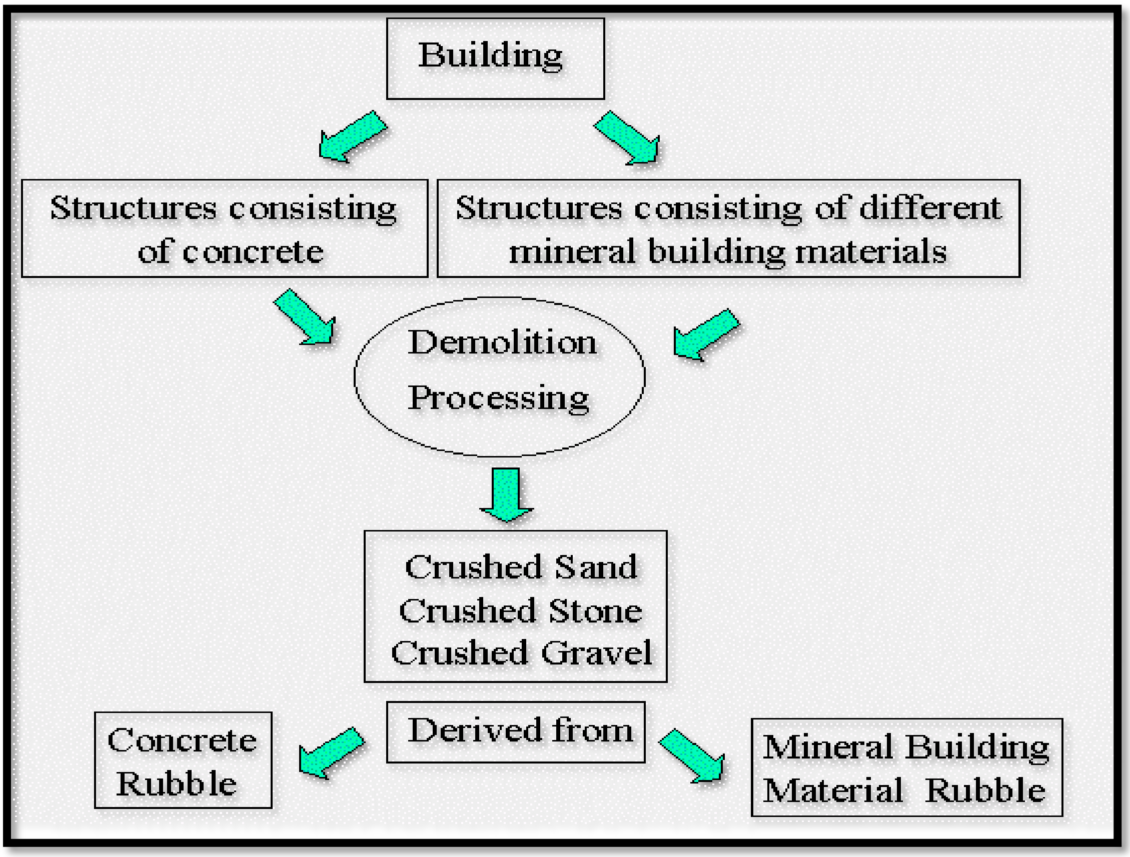

Figure 5: Flowchart of recycling process

2.3 Applications of RAC

1) Smaller pieces of concrete are used as gravel for new construction projects.

2) Sub-base gravel is laid down as the lowest layer in a road, with fresh concrete or asphalt poured over it. The US Federal Highway Administration may use techniques such as these to build new highways from the materials of old highways.

3) Crushed recycled concrete can also be used as the dry aggregate for brand new concrete if it is free of contaminants. Also, concrete pavements can be broken in place and used as a base layer for an asphalt pavement through a process called rubblization.

4) Larger pieces of crushed concrete can be used as riprap revetments, which are "a very effective and popular method of controlling stream bank erosion."

5) With proper quality control at the crushing facility, well graded and aesthetically pleasing materials can be provided as a substitute for landscaping stone or mulch.

6) Wire gabions (cages), can be filled with crushed concrete and stacked together to provide economical retaining walls. Stacked gabions are also used to build privacy screen walls (fencing).

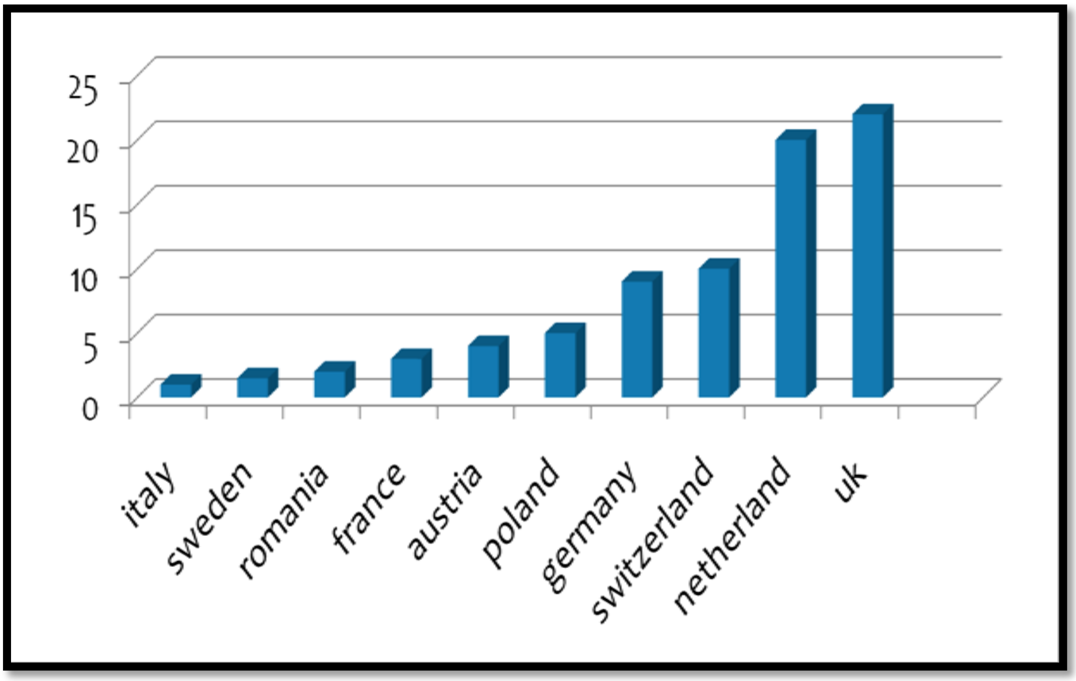

Figure 6: Uses of RAC in different parts of world

CONCLUSIONS

Recycling and reuse of building wastes have been found to be an appropriate solution to the problems of dumping thousands tons of debris accompanied with shortage of natural aggregates. The use of recycled aggregates in concrete proves to be valuable building material in technical, environmental and economical respect.

Recycled aggregate posses relatively lower bulk density, crushing and impact values and higher water absorption as compared to natural aggregate. The compressive strength of recycled aggregate concrete is relatively lower up to 15% than natural aggregate concrete.

1. Initial moisture states of RCA are one of the most important variables that impact strength and shrinkage.
2. When oven-dried RCA is used, strength is used to be greatly reduced but free shrinkage as observed in this study is low.
3. The creep to free shrinkage ratio for RAC is similar to that of normal concrete at 7 days under restrained conditions.
4. When greater volume of recycled fine aggregates and fly ash is use, then there is a reduction in free shrinkage of the specimens.

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