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Recycled Aggregate–An Alternative Construction Material

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Abstract—*Concrete has been proved to be a leading construction material for more than a century. It is estimated that at an annual rate of 1 m^3 per capita concrete has been produced globally, which results in increased consumption of natural aggregate. This situation leads to a question about the preservation of natural aggregates sources. Many European countries have placed taxes on the use of virgin aggregates.*
On the other hand over 1 billion tonnes of construction and demolition waste (C&D waste hereafter) is generated every year worldwide. The reason for this huge C&D waste is due to the structural deterioration, rearrangement of a city, expansion of traffic directions and increasing traffic load, natural disasters (earthquake, fire and flood), etc.
Recycling represents one way to convert a waste product into a resource. It has the potential to (1) extend the life of natural resources by supplementing resource supply, (2) reduce environmental disturbance around construction sites, and (3) enhance sustainable development of our natural resources. Thus it can be concluded that Recycled Aggregate fully or partially with natural aggregate is an alternative construction material.

Keyords: *Recycling of materials, Natural aggregates, Recycled Aggregates.*

1. INTRODUCTION

Concrete is the most consumable construction material. With the increase of renovation and construction of structures there is an increase of concrete demand. The concrete industry at present globally consumes 8 to 12 billion tones of natural aggregate annually which is suppose to increase in future. Thus there is a depletion of natural aggregates.

Also there are many sites at which natural aggregates is not easily available at economical distance, for this sites natural aggregates need to brought from other sites which include the cost of transportation and thus increase cost of project.

On the other hand demolition of old and deteriorated buildings and traffic infrastructure, and their substitution with new ones, is a frequent phenomenon of today age in a large part of the world. The main reasons for this situation are changes of purpose, structural deterioration, rearrangement of a city, expansion of traffic directions and increasing traffic load, natural disasters (earthquake, fire and flood), *etc.* For example, about 850 millions tones of construction and demolition waste are generated in the EU per year, which represent 31% of the total waste generation (*Shicong Kou and Poon, 2006*). The most common method of managing this material has been through its disposal in landfills. In this way, huge deposits of construction waste are created, consequently becoming a special problem of human environment pollution. For this reason, in developed countries, laws have been brought into practice to restrict this waste in the form of prohibitions or special taxes existing for creating waste areas.

One of the possible solutions to these problems is to recycle construction and demolition concrete waste to produce an alternative aggregate for structural concrete.

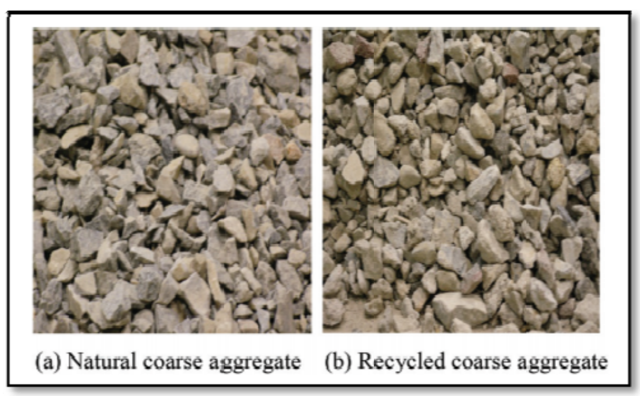

Fig. 1: Recycled Coarse Aggregate (*Thomas H.K. Kang 2014*).

2. RECYCLED CONCRETE AGGREGATE

Recycled concrete aggregate (RCA hereafter, fig 1) is the aggregates that generally produced by the crushing of concrete rubble, screening then removal of contaminants such as reinforcement, paper, wood, plastics and gypsum.

Concrete made with such recycled concrete aggregate is called recycled aggregate concrete (RAC).

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. Recycling of concrete is a relatively simple process. It involves breaking, removing, and crushing existing concrete into a material with a specified size and quality. The quality of concrete with RCA is very dependent on the quality of the recycled material used. Reinforcing steel and other embedded items, if any, must be removed, and care must be taken to prevent contamination by other materials that can be troublesome, such as asphalt, soil and clay balls, chlorides, glass, gypsum board, sealants, paper, plaster, wood, and roofing materials.

Recycled concrete aggregates have some mortar attached to its surface, which is the weakest point of RCA properties (*K.K. Sagoe-Crentsil et al, 2000*).

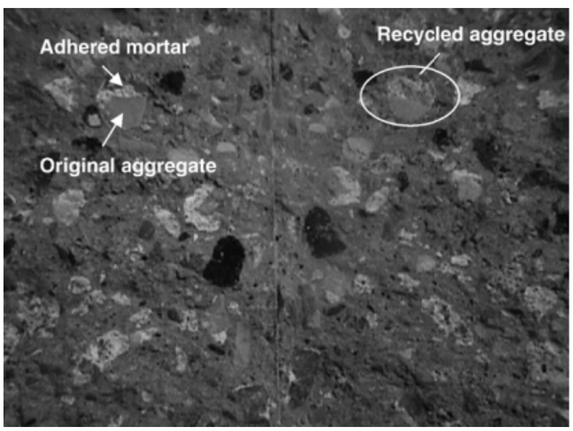

Fig. 2: Recycled aggregates concrete failure way by tensile (*M. Etxeberria et al, 2007*).

3. PHYSICAL PROPERTIES OF RCA

Based on available experimental evidence, the most important properties of recycled concrete aggregate (RCA) and concrete made with recycled aggregate (RAC) are briefly presented-

- Increased water absorption.
- Decreased bulk density.
- Decreased specific gravity.
- Increased abrasion loss.
- Increased crushability.
- Increased quantity of dust particles.

Khaldoun Rahal (2007) tested few properties of Recycled concrete aggregate and compare them with the Natural aggregates, the test results has briefly presented in the table1.

Nik. D. Oikonomou (2005), proposed the basic limits of various tests on Recycled Aggregates and these limits are presented in the table 2.

4. MECHANICAL PROPERTIES OF RAC

Since the properties of Recycled Concrete Aggregates is different from the natural aggregates this section deals with variation between the properties of RCA concrete compared to conventional NA concrete.

4.1 Compressive Strength

Compressive strength is the most the important property of concrete and is often taken as the index of the overall quality of concrete. Several factors can influence the compressive strength in RCA concrete, including the water/cement (w/c) ratio, the percentage of coarse aggregate replaced with RCA, and the amount of adhered mortar on the RCA. Most research recommended that, without changes to the mix involving adjustments to the w/c ratio, up to 25 or 30 % of coarse aggregate can be replaced with RCA before the ceiling strength is compromised. As the amount of the RCA in concrete is increased the compressive strength reduced. This reduction in compressive strength is approximately 8 to 25%, approximately 9 to 19%, and approximately 5 to 17% for replacement ratio 15%, 30% and 50% respectively (*Thomas H.K. Kang et al. 2014*). When mix proportion and slump of recycled aggregate concrete is same as normal concrete the strength of RAC is found 90% of the normal concrete (*Khaldoun Rahal 2007*). It had been proved by many researchers that the strength of the RAC is much affected by the strength of the parent concrete from which it had been derived. Since the Recycled Concrete Aggregate is derived from the demolished concrete structures certain amount of the mortar have remain attached with the concrete and this adhered mortar is the main factor due to which the compressive strength of the RAC has decreased and this reduction is of the order of approximately 10% (*K.K. Sagoe-Crentsil et al. 2000*). Water to cement ratio is the another factor that affect the strength of the concrete when the W/C ratio= 0.5 is kept same along with the same cement content=325 kg of cement/m^3 and the specimen for both the normal and Recycled aggregate concrete it is found that the compressive strength of RAC is 20-25% lower than that of the normal concrete (*M. Etxeberria et al. 2007*).

To increase the compressive strength of the RAC many attempt researchers. It has been found that when the certain amount of the fibres had mixed into the RAC and the specimens were tested there was an improvement in compressive strength and the compressive strength of the RAC had increased 22% as compare to RAC without fibre (*D. Suresh Kumar et al. 2013*). It has been verified by the many researchers that the compressive strength of the RAC is reduced with the increase in replacement ratio, but When steel fibres were used in the RAC it is found that there is an improvement in compressive strength with the replacement ratio as compare to the RAC without fibres (*M. Heeralal et al. 2009*). The result in the graphical form is shown below-

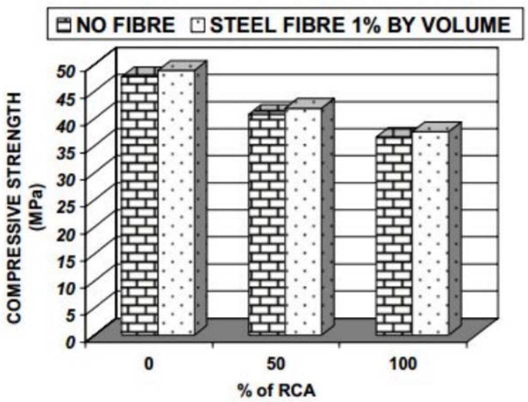

Fig. 1: Comparative study of Compressive strength of concrete with and without fibre (*M. Heeralal et al. 2009*).

Similarly in the process of increasing the compressive strength of RAC new mix design method other than the conventional method of mixing, was used. “Equivalent Mortar Volume Method” is one of them. RAC is prepared using EMV method and tested and it was found that the compressive strength is comparable or sometime higher than that of the normal concrete (*Abdelgadir Abbas et al. 2009*).

4.2 Tensile Strength

The tensile strength of concrete is relatively low, usually varying from 10% to 20% of the compressive strength. It may be measured indirectly in terms of tensile splitting strength of cylindrical specimens.

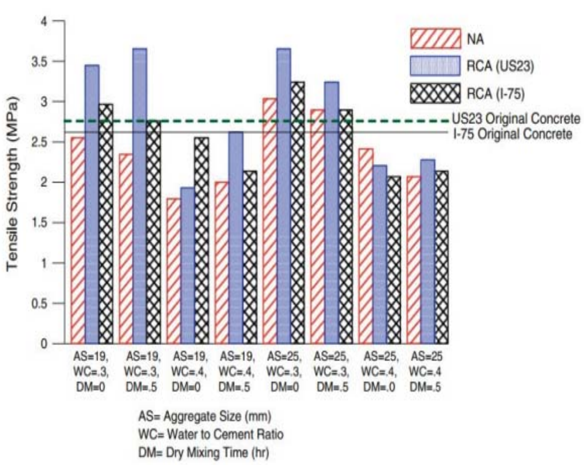

Fig. 2: Splitting tensile strength for RCA and NA concrete with varied aggregate size, w/c ratio, and dry mix time (*Tavakoli and Soroushian 1996*)

As far as the tensile strength of RAC is considered it is less affected by the recycled aggregate and has RAC has comparable tensile strength to that of the natural concrete (*Kang et al.2012*). W/C ratio is the main factor that affects the strength. RAC with low W/C ratio has improved tensile strength than RAC with high W/C (*L. Evangelista et al. 2010*). The following fig. 2 illustrate that RAC with low W/C has more strength than high W/C. Also the concrete aggregate size affect the tensile strength of the RAC, as the max size of aggregate is increased there was a decrease in the tensile strength (*Tavakoli and Soroushian 1996*).

4.3 Flexural Strength

Most of the study reveals that the increasing in the replacement ratio leads to decrease in the flexural strength.

In order to understand the flexural behaviour of the RCA, large scale beam testing had been done. The beam specimens with different replacement ratio were tested to find the flexural behaviour of the RAC and the result showed that the flexural strength of the RAC had been reduced with the increase in replacement ratio. Results shows that the reduction in flexural strength with replacement ratio is not linear but it shows that upto 30% replacement ratio the flexural strength is slightly lower or comparable to the flexural strength of the normal concrete (Thomas H.K. Kang et al. 2014). The long scale beam testing setup is shown in fig. – 3.

Silica fume is one of the cement replacement materials, when it is mixed in the RAC with some fibres it shows an improvement in the flexural strength. When in RAC mix consists 60% of Recycled fine aggregate and 40% natural sand and 15% of silica fume and 0.15% polypropylene fibre the ultimate load at beam testing are found 39.6kN which was 33.33% higher the conventional and other concrete beams (*M.Kaarthik, and K.Subrmanian 2014*). Similarly when “Equivalent

Table 1: Properties of the aggregates (*Khaldoun Rahal, 2007*)

Aggregate	Water absorption (%)	Specific gravity (SSD)	Specific gravity (oven dried)	Chloride content (% of cement mass)
Natural	0.68	2.86	2.84	0.14
Recycled	3.47	2.39	2.31	0.3

Table 2: Proposed basic tests and limits of RCA (*Nik. D. Oikonomou, 2005*)

Tests	Limits
Specific gravity, kg/m^3, min	2.20
Water absorption, %, m/m, max	3.0
Foreign ingredients, %, m/m, max	1.0

Organic ingredients, %, m/m, max	0.5
Sulphate ingredients, %, m/m, max (as SO_3)	1.0
Granulometric gradation	GSCT limits
Amount of sand, %, m/m, max (<4 mm)	5
Amount of filler, %, m/m, max (<0.063 mm)	2
Resistance to abrasion/degradation by the use of L.A. machine, %, max	40
Soft granules, %, m/m, max	3
Soundness, loss, %, max	10
Sand equivalent, %, min	80

Mortar Volume method" had been used for the RAC mix design the results shows that the flexural performance of the RAC is comparable or even superior to the natural concrete (*Gholamreza Fathifazal et al. 2009*).

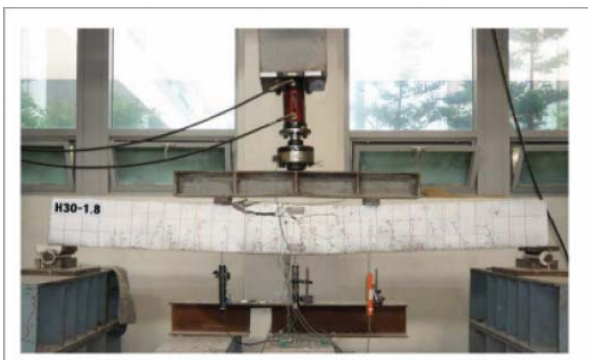

Fig.3: Beam testing for flexure (*Thomas H.K. Kang et al. 2014*).

5. CONCLUSION

Concrete made with 100% of recycled coarse aggregates has 20–25% less compression strength than conventional concrete at 28 days, with the same effective w/c ratio. But to achieve the same strength as the conventional natural concrete Recycled aggregates requires 4–10% lower effective w/c ratio and 5–10% more cement.

Although the strength of Recycled Aggregate Concrete is lesser than that of the conventional concrete but it is to be noted that the strength of RAC is higher than the theoretical values that obtained from the code.

Therefore it can be concluded that RCA is an alternative construction material for 21st century.

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