Comprehensive Study of Recycled Aggregate and their Physical Assessment for Suitability in Concrete

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Abstract

With the emphasis on sustainable development in civil engineering practises the use of recycled aggregate have already started in major projects in developed countries in past decade which include many European, American, Russian and Asian countries. Extensive research has been carried out worldwide on the use of recycled aggregate in concrete. Still there is lack of comprehensive specifications and guidelines regarding use of recycled aggregate in many countries. This article describes the study and research work conducted on recycled aggregate by authors. Different physical properties tests were performed on recycled aggregate to examine its consistency with specifications provided by Indian Standards. Compressive strength test on concrete with varied proportions of recycled aggregate were conducted and evaluated against natural aggregate. All tests were conducted in accordance with Indian standards. Results obtained demonstrate that although significant variations are noticed between the physical properties of recycled aggregate and natural aggregate, yet values are consistent with BIS[1] specifications. Compressive strength test indicate that 20% substitution of natural aggregate with recycled aggregate in concrete have no significant impact on strength whereas the concrete prepared with 100% recycled aggregate exhibits compressive strength which is on the average 82% of that of natural aggregate.

INTRODUCTION

The use of recycled materials in the construction sector has been occurring over the past years with varying degree of success. With an increasing scarcity of natural resources, there is an increasing demand and interest in aggregate from non-traditional sources such as from industrial by-products and recycled construction and demolition wastes. Recycled aggregate encompass reused construction products and pavement materials, all of which were once considered waste and dumped landfill. Replaced and reconstructed old roads and buildings have become major sources of "recyclable materials."In some applications, recycled aggregate can compete with natural aggregate on price and quality. The increasing limitations imposed on the use of landfills, as well as the higher costs imposed on landfill use, are making the recycling of aggregate economically viable.

RECYCLED AGGREGATE (RA)

Recycled aggregate are aggregate obtained by the processing of withered material which were earlier used in construction. Use of recycled aggregate from roads and building is growing as supplement to natural aggregate in construction due to dwindling natural sources .Recycled aggregate currently account for less than 1% of the total demand for construction aggregate, but this amount is continuously accelerating.

Based on their source of production, RA can be categorised into following types:

I. **Recycled Concrete Aggregate (RCA):** RCA are aggregate generated from construction and demolition (C&D) waste concrete such as rehabilitation of bridges, buildings, sidewalks and other structures. According to 'Cement Concrete & Aggregate, Australia'[2] - Coarse recycled concrete aggregate (RCA) is produced by crushing sound, clean demolition waste of at least 95% by weight of concrete, and having a total contaminant level typically lower than 1% of the bulk mass'. Dwindling natural sources, senescent infrastructure, decreasing landfill and environmental apprehensions linked with C&D waste work together to increase concrete recycling .There is high potential of RCA in wide range of engineering applications. In this article, our main focus is on RCA.

II. **Recycled Asphalt Pavement (RAP):** It is the term given to removed and reprocessed pavement material containing asphalt and aggregate. These materials are removed from demolished roads, parking lots and runways. When properly crushed and screened, RAP consists of high quality well graded aggregate coated by asphalt. The majority of RAP produced is recycled and used.RAP is almost always returned back into the roadway structure in some form usually incorporated into asphalt by means of hot or cold recycling but are also used as aggregate in base or sub-base construction. In US more than 100 million tonnes of dilapidated asphalt pavement are recuperated every year. About 80 percent of the recovered material is recycled and remaining is deposited into landfills. Two-thirds of the recycled material is used as aggregate for road base. The remaining portion is reused as aggregate for new asphalt hot mixes.

III. Reclaimed Aggregate: This is the aggregate extracted from the surplus fresh concrete that has been returned to batching plant, by separating it from mortar by washing it with water. Aggregate are screened and water may be reclaimed. Large volume of water is required for concrete washing and its uncontrolled disposal can lead to problems of environmental impacts. The handling and disposal of the wash water contaminated with cement and fine sand presents a challenge to the concrete producer. So all RMC plants have some type of wash-water recycling system to minimise the need for resource consents to dispose of water.

ADVANTAGES OF RECYCLED AGGREGATE

Following are the advantages associated with use of recycled aggregate:

I. Resources Preservation: As the infrastructure is expanding due to mushrooming population, the demand for aggregate is also rising as a result so natural sources are continuously declining day by day. Recycling waste concrete into usable aggregate reduces the demand for virgin aggregate from pits and quarries and yields environmental benefits by preserving dwindling natural resources.

II. Reduction in Costs and Energy Consumption: Recycling conserves the use of natural aggregate and associated environmental costs of exploitation and transportation. Transportation and delivery at all stages of concrete production is the second largest source of pollution after carbon emissions from cement manufacturing kilns. Any saving in transport by using natural aggregate reduces both the cost and environmental burden. The use of mobile crushing plants strategically located can reduce the demolition concrete and recycled aggregate cartage distance and can be justified on large projects.

III. Land Preservation: Recycling concrete squander preserves the use of landfill for materials which cannot be recycled. Earth available for landfill is almost limited but C&D waste is increasing. In such conditions recycling proved to be a best substitute for land filling. In some countries, levy was introduced in past years on landfill and this will be more in future as landfill sites are becoming scarcer. Levies on landfill dumping make aggregate recycling an ideal option.

IV. Enhanced CO2 Absorption: Approximately half of the CO_2 emission from cement production is emitted by the calcination of limestone. During carbonation, hardened concrete absorbs the same amount of CO_2 and it mainly depends on the surface area of the concrete exposed to the atmosphere. It was found[3] that 60-80% of CO2 released during manufacturing of cement is reabsorbed by the concrete mixtures within 25-30 days of exposure. When C&D waste is converted back to RCA, the surface area is largely increased so enhances the CO2 absorption in the secondary stage. (i.e. after demolition stage)

OBSTACLES IN USE OF RECYCLED AGGREGATE

The use of concrete with 100% substitution of natural aggregate by recycled aggregate must be properly managed and controlled otherwise it is likely to have a harmful impact on most of the concrete properties. Following are the drawbacks of recycled aggregate concrete:

I. Variation in Physical Properties: When crushing of C&D waste takes place, there is some mortar left adhered to the surface of the aggregate. The presence of adhered mortar on the surface of crushed concrete aggregate generally degrades the quality of the recycled aggregate and consequently the properties of the fresh and hardened concrete made from it. This adhered mortar can limit the strength of recycled aggregate concrete particularly where the parent concrete strength is lower than the target compressive strength of the recycled aggregate concrete. Workability of recycled aggregate concrete also decreases due to higher water absorption by recycled aggregate. Adjustments in the mix design would be necessary to overcome the effect of RCA on the workability, absorption, strength and shrinkage.

II. Consumer's Uncertainty: There are numerous market restrictions and technical challenges when developing a market for secondary products. Consumer uncertainty about the quality and consistency of product is notable barrier among these. Recycled aggregate lacks in practical performance and engineering statistics. Such information is necessary to aid the appropriate design codes to guide product specification and performance information on recycled aggregate. Presently available manual is HB 155:2002[4] 'Guide to the use of recycled concrete and masonry materials' published by Standards Australia.

III. Presence of Contaminants: Presence of significant amount of contaminants including asphalt, soil, clay balls, wood, plaster etc can effectively increase the processing cost to high extent, resulting in diminution in the use of recycled aggregate and then can only be used as sub base material in roads.

SOME FACTS AND FIGURES*

- Recycled aggregate account for 28% of all aggregate sold in UK[5].
- In USA[6], 13.8 million tonnes recycled concrete accounting for $103 million was reported as recycled in 48 States in 2011.
- According to a Survey[6] in USA in 2011, five states California, Illinois, Michigan, Virginia, and Minnesota were identified among the highest consumers as well as large suppliers of RCA. Their combined total was 7.1 million tonnes, an increase of 15% compared with their combined total of 2010.
- In New Zealand[7] 27% of the total waste generated is construction and demolition waste (C&DW), and of this concrete represents 25%, i.e. 7% of the total waste.
- About[8] five million tonnes of recycled concrete and masonry are available in Australian markets principally in Melbourne and Sydney, of which 500,000 tonnes is RCA.
- The Dutch standard VBT 1995[8] allows up to 20% replacement of natural aggregate with RCA or recycled mixed aggregate (RMA) without a need for additional testing for all concrete up to a characteristic strength of 65 MPa and all relevant environmental classes (equivalent to specific maximum levels of W/C).
- HB155:2002[4] states that in grade 1 concrete with maximum strength limit of 40Mpa,class 1A RCA with brick content less than 0.5% and total contaminants less than 1% can be substituted upto 30% and in grade 2 concrete with max specified strength limit of 25Mpa ,class 1A RCA or class 1B RCA can be used with 100% substitution.
- Research[9] in the US demonstrated that all recycled aggregate, except that from the poorest concrete, met the minimum LA abrasion resistance requirements specified in ASTM C33/C33M-11a[10].
- In Nordic countries[3], 0.6 to 1.2 million tonnes C&D waste was generated annually and RCA were calculated to be in the range of 0.2 to 1.0 million tonnes i.e. 30 to 90%.

RECYCLED AGGREGATE AND NATURL AGGREGATE: PHYSICAL ANALYSIS

Experiments were conducted on both recycled and natural aggregate for the analysis of physical properties such as specific gravity, bulk density, water absorption, aggregate impact value, gradation and fineness modulus and results are compared. Different materials used are given below:

Cement: UltraTech Ordinary Portland cement of 43 grade conforming to IS: 8112:1989[11] was used in making concrete samples. The physical properties of OPC 43 grade cement are given in table 1.

Table 1. Physical Properties of OPC 43grade Cement

Type of Cement		UltraTech OPC 43
Specific Gravity		3.10
Normal Consistency (%)		34
Setting Time (minutes)	Initial	86
	Final	285
Compressive Strength (MPa)	3 days	17.27
	7 days	33.34
	28days	44.24

Water: Potable water conforming to IS: 3025:1964[12] is used for mixing.

Aggregate: Both fine and coarse aggregate were collected from site 'Construction of District Administrative Complex, Ferozpur'. Fine aggregate used was same in all samples. Waste concrete cubes were also taken from same site and crushing of cubes upto size 20mm was done manually. The source of both the aggregate was same. Care is taken to prevent contamination by dirt or other waste building materials such as plaster or gypsum.

The tests were conducted at PIDB[15] empanelled and ISO certified laboratory of 'Global Engineers and Consultants' in Bathinda which is well known city of Punjab and its geographical coordinates are 30°13'39.02"N, 74°57'7.42"E.

RESULTS AND DISCUSSION

Results obtained from physical investigation of both recycled and natural aggregate are compared in table 2.

Table 2. Physical Properties of Fine Aggregate(FA), Recycled aggregate (RA) and Natural aggregate (NA)

S.No	Aggregate Properties	FA	RA	NA
1.	Bulk Specific Gravity (OD)	-	2.45	2.69
2.	Bulk Specific Gravity (SSD)	2.51	2.55	2.71
3.	Apparent Specific Gravity	-	2.73	2.74
4.	Water Absorption (%)	2.22	4.22	0.52
5.	Bulk Density (kg/m3)	1640.32	1473.98	1598.22
6.	Aggregate Impact Value (%)	-	25.42	15.17
7.	Fineness Modulus (%)	2.86	6.72	6.88

* Based on literature reviewed

Although results obtained were consistent with BIS[1] specifications used for aggregate, considerable variations were found out between physical properties of Recycled and Natural aggregate. The primary factor responsible for these differences is the presence of adhered mortar on the surface of the crushed concrete aggregate which generally degrades the quality of the recycled aggregate and consequently the fresh and hardened properties of concrete made from it. The bulk density of recycled aggregate was lower than that of natural aggregate. The specific gravity (bulk and apparent) of recycled aggregate was found less than natural aggregate because of reduced bulk density and greater water absorption. The water absorption and aggregate impact value of recycled aggregate were highly influenced due to adhered cement paste to aggregate surface which increases its porosity.

RECYCLED AGGREGATE CONCRETE

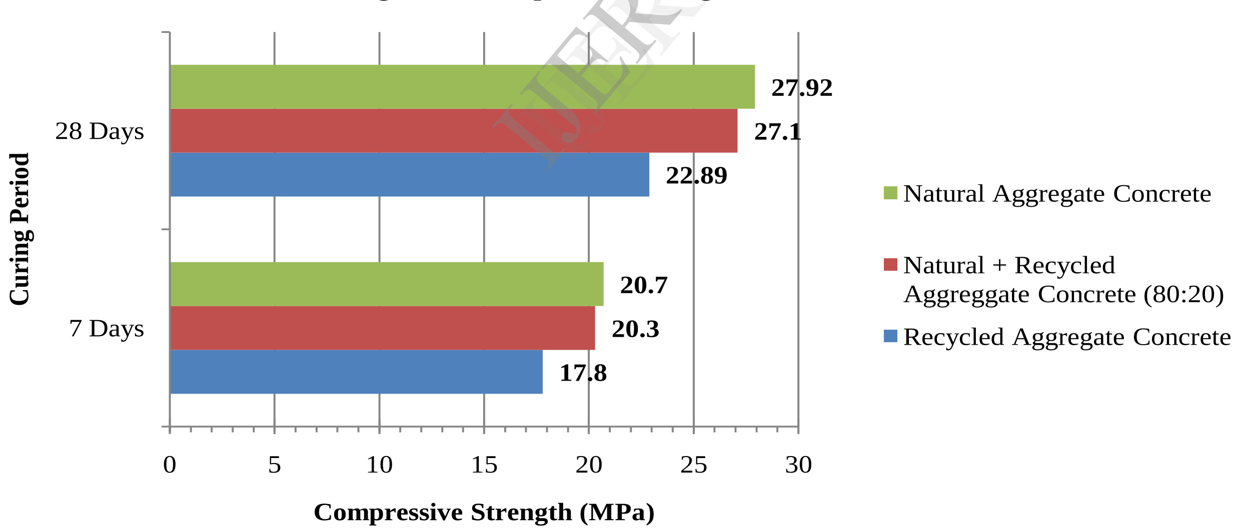
Mix design (M20) was prepared as per specifications given in IS: 10262:2009[13]. Water cement ratio was kept 0.50. Three types of concrete samples were prepared, first sample (A) was made with 100% natural aggregate, second sample (B) with 100% recycled aggregate and in third type (C), 80% natural aggregate and 20% recycled aggregate were used.

Tests conducted encompass dry density and compressive strength of hardened concrete. Compressive strength test was conducted according to IS: 516:1959[14] at 7 and 28 days. Results obtained are tabulated below and are also demonstrated in following bar chart.

Table 3. Test results of Recycled aggregate concrete and Natural aggregate concrete

Sample Type	Dry Density (kg/m3)	Compressive Strength (MPa)	
		7 days	28 days
Sample A (NA)	2363.40	20.71	27.92
Sample B (RA)	2233.92	17.80	22.89
Sample C(NA:RA:: 80:20)	2348.67	20.30	27.10

Figure 1. Compressive Strength Bar Chart



Approximately 10% more water than design value was required at the timing of mixing to make recycled aggregate concrete workable whereas it amounts to 2% in case of concrete prepared with mix proportion of recycled aggregate and natural aggregate. Dry density of recycled aggregate concrete came out to be less than natural aggregate concrete as water absorption of recycled aggregate is higher. The compressive strengths of recycled aggregate concrete and natural aggregate concrete are 22.89N/mm^2 and 27.92 N/mm^2 at 28 days. The results illustrate that strength of recycled aggregate concrete is on average 82% of natural aggregate concrete, one reason for which is adhered mortar which gets dislodged under test load. However, recycled aggregate concrete still satisfy Indian standards accepted requirements and can be used for construction purpose.

CONCLUSION:

Research conducted hereby indicates that although substantial differences were found in some physical properties of Recycled aggregate which was extracted from C&D waste as compared to Natural aggregate yet concrete produced from recycled aggregate gives satisfactory results under standard test conditions and results are consistent with IS: 456-2000[15] and proper alterations in the mix design would be crucial to overcome the effect of RCA on workability, absorption and strength.

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