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Impact of Recycled Construction Waste Aggregates on the Performance of Pavement Concrete

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ABSTRACT:

India's fast urbanization and infrastructure growth have resulted in a large rise in construction and demolition (C and D) waste, which presents major logistical and environmental problems. At the same time, there is growing concern over resource depletion and ecological degradation due to the growing demand for natural aggregates in pavement construction. The potential of using recycled construction waste aggregates (RCA) in pavement concrete as a sustainable substitute for traditional aggregates is examined in this study. The study methodically assesses the performance, durability, and mechanical properties of concrete with different RCA proportions. Tests for water absorption, modulus of elasticity, abrasion resistance, compressive strength, and flexural strength are examples of experimental analyses. The results show that recycled aggregates, in particular, can perform on par with natural aggregates when processed properly and mix design improved. Every year world produces around 10bn tons of concrete in a year and it is estimated that this amount is going to rise to a staggering 230bn tones in the next 40 years, as most of the building material is not environment friendly as its production involves some serious concern to our ecosystem. So, efforts are being done for the introduction of more energy efficient methods which can save our environment as well as cost at the same time. Every year new structures are replaced with the older ones and the building waste generated by the older structures are dumped in the unlicensed sites which ultimately cause land filling which is a serious environmental problem but our solution and future of the construction lies in this problem only. The waste generated by the demolished structures can be recycled to use again in the construction of the new building which is a greener and cost-effective method.

Keywords: Aggregates, Pavement, Compressive Strength, Recycled Waste

Introduction:

The rapid pace of urbanization and infrastructure development has led to a significant increase in the generation of construction and demolition (C&D) waste across the globe. In developing countries like India, this trend is particularly prominent due to booming construction activities and limited awareness of sustainable waste management practices. C&D waste, if not properly managed, poses serious environmental, economic, and logistical challenges, including land degradation, pollution, and the overuse of natural resources. At the same time, the construction industry continues to rely heavily on natural aggregates for concrete production, resulting in the depletion of riverbeds, increased carbon footprint, and ecological imbalance. In this context, the partial or full replacement of natural aggregates with recycled aggregates sourced from C&D waste emerges as a viable and environmentally sustainable alternative. Recycling C&D waste not only reduces the demand for virgin materials but also diverts waste from landfills, contributing significantly to circular economy principles. The use of recycled construction aggregates in concrete, particularly for rigid pavements, offers promising opportunities for sustainable road infrastructure development without compromising structural integrity or performance. However, the incorporation of recycled aggregates in pavement concrete brings forth several challenges, such as variations in material quality, higher water absorption, and potential reductions in mechanical properties. These factors necessitate a detailed investigation into the engineering performance of recycled aggregate concrete (RAC), particularly in terms of strength, durability, workability, and long-term behavior under traffic loading conditions.

This ***work*** aims to evaluate the impact of using recycled C&D waste aggregates as a partial replacement for natural aggregates in pavement concrete. It focuses on assessing the physical and mechanical properties of the resulting concrete mix, its suitability for rigid pavement applications, and its potential to contribute to environmentally responsible construction practices. The study further explores the economic and ecological benefits of such substitution, with the broader objective of promoting sustainable material use in road construction.

Recycled Construction Waste Aggregates for Pavements:

Construction and demolition (C&D) waste constitutes a significant portion of solid waste generated globally, primarily from activities such as building renovation, road construction, and structural demolitions. These wastes typically comprise concrete debris, bricks, asphalt, wood, steel, and other construction materials. Among them, concrete waste is the most abundant and possesses high potential for recycling as coarse aggregates in new concrete production. When properly processed, the crushed concrete debris can be used as recycled aggregates to partially replace natural aggregates in various construction applications, including rigid pavement construction.

In pavement engineering, concrete pavements (also known as rigid pavements) require materials that ensure high strength, durability, and long-term performance under repeated traffic loading and environmental stresses. Natural aggregates, conventionally used in concrete, are becoming increasingly scarce due to over-extraction and environmental regulations. This has necessitated the search for sustainable alternatives that can perform comparably without compromising the structural integrity of the pavement. Recycled construction waste aggregates (RCA) offer an environmentally and economically viable solution in this regard.

The use of RCA in pavement concrete contributes to waste minimization, conserves natural resources, and supports circular economy principles. These aggregates, however, differ from natural aggregates in terms of physical and mechanical properties. Recycled aggregates tend to have higher porosity, lower density, and increased water absorption due to the presence of residual mortar adhered to their surfaces. These characteristics can influence the workability, strength, and durability of concrete, making it imperative to study their effects thoroughly before large-scale implementation.

In recent years, many studies have shown promising results in using RCA for structural and non-structural applications. For pavement use, where service life and load-bearing capacity are critical, it becomes essential to establish the optimum replacement level of natural aggregates with RCA that ensures satisfactory performance. Moreover, incorporating recycled aggregates in pavement design aligns with sustainable development goals by reducing the carbon footprint associated with the extraction, processing, and transportation of virgin materials.

Fig 1 Recycled Construction Waste Aggregates for Pavements

Indian Scenario:

The ministry of Environment, Forests and climate change in 2010, put the annual estimate of C&D waste at 10-12 million tonnes. The central pollution board settled for 12 million tonnes in 2011, but its guidelines document of 2017 has upped the estimate to 25-30 million tonnes, based on the information from ministry of urban development. The most recent estimate of C&D waste shows 165 million tonnes in Indian cities, jointly prepared from the period of 2009-13. IL&FS has set up India's first operational large-scale C&D recycling facility in DELHI. The plant can help to ease the pressure of about 5000 tonnes of C&D waste that Delhi generates per day and up to 2016 the plant has helped save over 45 acres of land urban worth over Rs. 400crores by reducing the burden of the landfills.

Table 1 Quantity of various constituents generated per year

CONSTIUENTS	MILLION TONNES/YR
Soil, sand & gravel	4.20 to 5.14
Brick and masonry	3.60 to 4.40
Concrete	2.40 to 3.67
Metals	0.60 to 0.30
Bitumen	0.30 to 0.25
Wood	0.25 to 0.30
Others	0.10to 0.15

Fig 2 Different constituents of C&D waste

Objectives of the Study

- To study the physical and mechanical properties of recycled construction waste aggregates and compare them with natural aggregates.
- To evaluate the performance of recycled aggregate concrete in terms of compressive strength, flexural strength, workability, and durability.
- To develop such a mix which permits the usage of higher percentage of recycled aggregates in concrete without compromising on its strength properties much.
- To run various test of the sample crafted out of RCA (fresh as well as hardened concrete) and also on the nature of the recycled coarse aggregates.
- Based on the result of this research, recommendation on the wider scale for the use of RA in structural and non-structural concrete and design of the safer guidelines for the use of RA in construction industry.

Methodology:

The research methodology includes the following key steps:

- Collection and processing of recycled aggregates from construction waste sources.
- Characterization of physical properties such as specific gravity, water absorption, and crushing value.
- Preparation of concrete mix designs with varying percentages of recycled aggregate replacement.
- Conducting standard laboratory tests for workability (slump), compressive strength, and flexural strength at different curing periods.
- Comparing the performance results of recycled aggregate concrete with conventional concrete.
- Analyzing the data to determine the optimal replacement level and assessing environmental and economic implications.

Mix Design Procedure:

M30- The mix design M30 was designed for slump 40-70 mm. Admixture (Aster Super-plasticizer 200) is used. The mix proportion is taken by weight is shown Table 2.

Table 2 Constitution of mixes

Cement	Sand (fine aggregate)	Coarse aggregate (20mm)	Coarse aggregate (10mm)	Water	Admixture
1	1.87	2.43	0.94	0.42	5.26 (gm)

Mass of Cement (OPC 53 Grade)	380Kg/m^3
Water	160
Sand	711
Coarse Aggregate	1283
20mm	924
10mm	359
Admixtures	1.9
Water/cement	0.42

Percentage Replacement of RA

Two mixes M20 & M30 will be designed for same replacement of recycled aggregates with natural aggregates. RA00, RA50, RA100 are the Four batches prepared for M20 & M30 consecutively, overall, eight batches were made. The initial mix batch will be 100% natural aggregate mix batch (RA00 means replacement of recycled aggregate with natural aggregate is 0%), second mix batch was 50% natural aggregate and 50% recycled aggregate (RA50), and fourth mix batch was 0% natural aggregate and 100% recycled aggregate (RA100). M20 & M30 mix design has different water cement ratio, cement

content, different proportion of coarse and fine aggregates. The only main difference is that admixture is used in M30 and not used in M20 mix design.

Results

Series of test was accomplished on the natural and recycled aggregates, concrete cubes & cylinders to get the strength characteristics of the recycled concrete aggregate for probable application in normal strength concrete. The compressive, tensile and bond strengths of concrete are relatively important mechanical properties of any hardened concrete including recycled aggregate concrete. The recycled concrete must embrace the same conventional concreting practices to guarantee the hardened concrete properties. This chapter will discuss on the results that obtained from the testing and compare them to the standards accordingly. The results are such as abrasion test, impact value test, water absorption & specific gravity of aggregates, slump test, compression test and split tensile test.

Table 3 Compressive Strength

S. No.	Batches	Age of cube (days)	Wt of Concrete Cube (Kg)	Area of Cross Section (mm)	Load (kN)	Compressive Strength (N/mm2)	Average Compressive Strength (MPa)
1.	M30 RA00	28 28 28	8.1 8.1 8.1	150x150 150x150 150x150	688.5 700.8 693	30.60 31.15 30.80	30.85
2.	M30 RA50	28 28 28	8.1 8.1 8.1	150x150 150x150 150x150	717.75 777.3 735.2	31.90 34.55 32.70	33.05
3.	M30 RA100	28 28 28	8.1 8.1 8.1	150x150 150x150 150x150	622.1 572.8 535.5	27.65 25.46 23.80	25.05
4.	M20 RA00	28 28 28	8.1 8.1 8.1	150x150 150x150 150x150	495 469.1 493.87	20.40 20.85 21.95	21 .53
5.	M20 RA50	28 28 28	8.1 8.1 8.1	150x150 150x150 150x150	515.2 535.8 510.7	22.90 23.80 22.70	23.24
6.	M20 RA100	28 28 28	8.1 8.1 8.1	150x150 150x150 150x150	433.2 441.3 395.7	19.22 19.26 17.59	18.26

LA Abrasion Test Result Analysis

The LA abrasion value of the recycled aggregate is 26.77% of 12-20mm sized fraction. This value is higher than that of virgin aggregates which has abrasion value 17.90%. Recycled aggregates are well washed and prepared for the testing and it shows good strength but not more than virgin aggregates. Aggregates with lower abrasion value percentage are comparatively stronger. It is possible to allow for the abrasion loss in the mixture proportion because the aggregate itself does not break down. Instead, the maximum LA abrasion value for aggregates is 30% for cement concrete pavement course. Therefore, the result is acceptable in this experiment.

Table 4 Abrasion value comparison

Aggregate Type	Abrasion value %
RA	30.32
NA	24.40

Impact Value Test Result Analysis

The impact value of the recycled aggregate is 17.03% of 12-20mm sized fraction. Two tests were conducted and the mean value is 17.30% which is good but not better than natural aggregate whose mean value of two tests are 9.90 %. Besides, both the aggregate types are exceptionally strong as their value lies below 10% according to the transportation engineering lab manual 2013.

Aggregate strength percentage lower than 10% is exceptionally strong and those vary between 10-20% will be categorized as strong while those of vary between 20-30% will be taken as satisfactory for cement concrete surface course and those which varies from 30-45% will be taken in the category of cement concrete base course while not as surface course. And here we have the aggregate better than 10% which can be easily used in the structural cement concrete. Therefore, the results are easily acceptable in this experiment.

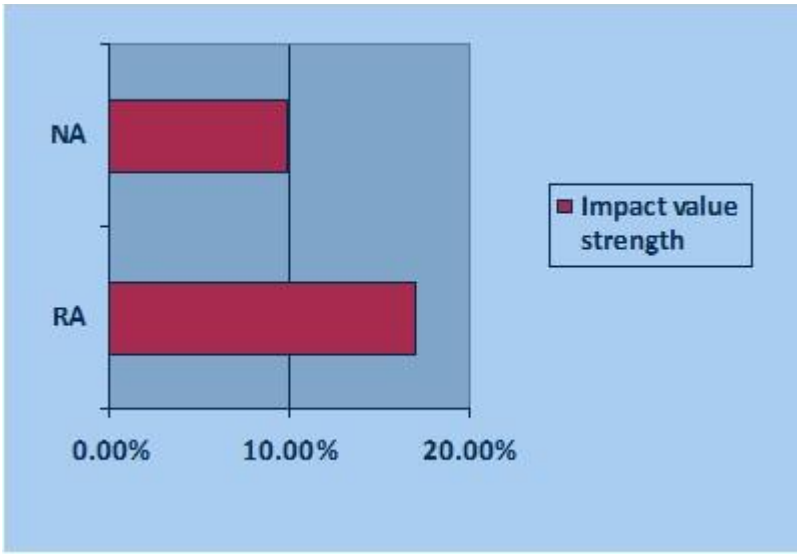

Fig 3: Impact value comparison

Water Absorption and Specific Gravity Test Results and Analysis

The results have shown the higher water absorption of 1.95% of recycled aggregates. Because it has little mortar attached to the surrounding of the recycled aggregate. It indicates that the cleanliness & washing of the recycled aggregate is still need to be done properly to get the results near to as of natural aggregates. The percentage of water absorption for the natural aggregates is 0.98% which is better than that of recycled aggregates. The average permissible water absorption of aggregate should not be greater than 2%. Though, normal weight aggregates of higher absorption value is acceptable depends on local performance. As far as concern about this experiment, the water absorption of recycled aggregate does not exceed permissible value so it is acceptable. Now concerning about specific gravity of the recycled aggregates, it shows the result varies between 2.26 – 2.48 which is nearly 2.37 by taking average of two readings, while the specific gravity of natural aggregates varies around 2.57 – 2.65 which is nearly 2.61 by taking average of two readings. The normal specific gravity varies from 2.5 to 3. Specific gravity helps in identification of stone, to measure the strength and quality of the aggregates, in such case, quality does not matter much where strength of the aggregates has passed their test (as stated in the earlier test analysis) so this can also be accepted. Comparison of water absorption, specific gravity.

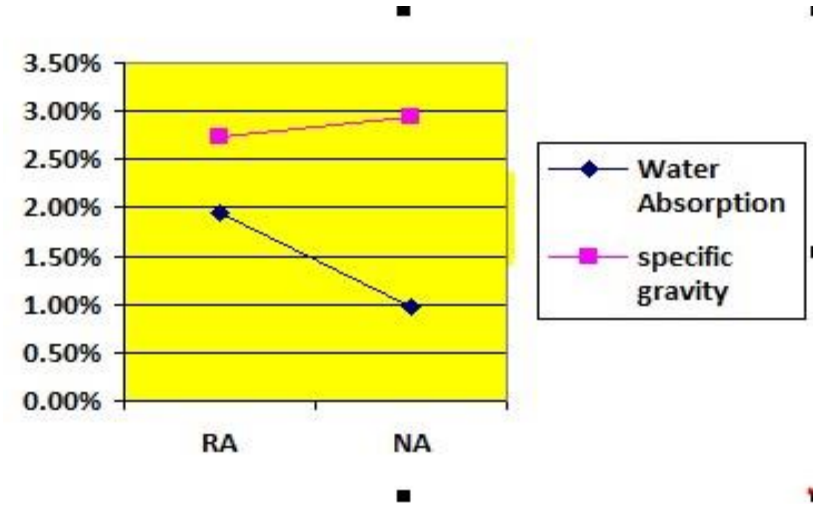

Fig 4: water absorption and specific gravity

Conclusion

The workability of recycled aggregate concrete is slightly less because the mortar adhered from the original concrete makes the recycled aggregates little porous and absorptive than its natural equivalent but around the limits, the absorption capacity of recycled aggregate is just twice of natural aggregates absorption capacity but under the limits.

The recycled aggregate test results showed that the recycled aggregate concrete can give strength almost similar to an equivalent concrete with natural aggregates. The use of recycled aggregate does not gravely affect the compressive strength of the concrete. Using 50% of recycled coarse aggregate in concrete mixes shows comparatively better compressive strength than conventional aggregate concrete in M30 mix while little less compressive strength of M20 mix with same percentage replacement but still crosses the target strength.

The behaviour of recycled aggregate concrete is the same as natural aggregate concrete under split tensile loading in both Mixes but a bit low in RA50 batch of both mixes.

- The study demonstrated that concrete mixes incorporating up to a certain percentage of RCA exhibited satisfactory compressive and flexural strength, along with acceptable performance in durability parameters such as water absorption, abrasion resistance, and surface wear.
- Although a slight reduction in mechanical performance was observed at higher replacement levels, the results remained within acceptable limits for low to medium traffic pavement applications.
- Compression, & split test mean values of RA50 batch for M20 & M30 mixes have well passed the standards as shown in the results.
- So there is a noteworthy conclusion that after confirmation of the laboratory test results; compressive strength & split tensile strength & of recycled aggregate concrete can meet the requirements of normal strength of standards of conventional concrete.
- Workability of the concrete varies from 51-66mm for M30 and 18-27mm for M20 which are around the limits 50 & 25mm respectively. It is considerable and hence can be achieved by adding super plasticizers in the mix especially when the mix contains RA not more than 50% according to the test results of this project.
- Importantly, the use of RCA offers substantial environmental benefits, including the reduction of construction and demolition waste, conservation of natural aggregate resources, and minimization of carbon footprint associated with material extraction and transportation.

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