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Analytical Study of Recycled Concrete Aggregate as Partial Replacement of Natural Aggregate in Bitumen Concrete

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ABSTRACT

The development of any country relies upon the transportation modes, networks and the manners by which they are being kept up with. Similar turns out to be true for second highest populated and developing country like India. For interfacing the regions and keeping up with smooth progression of traffic, the construction of new and developed roads are a must. A similar will be accomplished with the execution of the Bharatmala project. Under the plan, a large group of new roads will be set down in the country. Total road construction as per the draft of the scheme, government and the ministry will strive to complete new roads, which will add up to a 34, 800 kms. National highways account for 2% of the total road network and carry over 40% of complete traffic. Highway development in India expanded at 17.00% CAGR between FY16-FY21. In spite of pandemic and lockdown, India has developed 13,298 km of highways in FY21. In FY21, 13,298 kms of highway was developed across India. India Union Minister Nitin Gadkari announced that India holds the world record for fastest road construction. India has entered Guinness World Records by building a 2.5 km 4-lane concrete road within 24 hours. National Highways Authority of India (NHAI) plans to construct national highways in 2022-23 at a pace of 50 km per day.

The need for sustainable bitumen highway design and construction is becoming a priority within the transportation industry. This trend is necessitated by the high diminishing rate of construction materials, pressing demand on existing landfill sites, rising dumping fees, and reduced emissions into the environment. Recycled Concrete Aggregates (RCA) as sustainable aggregates in Hot Mix Asphalt (HMA) is therefore investigated in this research article. This study examined the incorporation of various fractions of RCA at 25%, 50%, 75% and 100% replacement to fresh aggregate.

KEYWORDS: *Reuse Aggregate, Bituminous Concrete, Pavement Construction, Construction Industry*

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1. INTRODUCTION

1.1. General

At present many pavement construction projects are undertaken in various parts of country some of the projects which are more than 500 kms like Delhi to Mumbai expressway (1,350 km), Amritsar to Jamnagar expressway (1,257 km), Mumbai to Nagpur Expressway (701 km), Delhi to Amritsar to Katra Expressway (687 km), Ludhiana to Bhatinda to Ajmer Expressway (600 km), Meerut to Prayagraj Expressway (594 km) etc. which clearly shows the demand for the resources of bituminous concrete which are increasing day by day. The constituents of bituminous concrete are coarse aggregate, fine aggregate, filler material, and bitumen. The materials, used for this study, are Aggregate. The production of coarse aggregate is also getting reduced due to the restriction imposed on aggregate crushers to minimise air pollution. A huge quantity of raw material consumption in construction industry becomes one of the main factors that cause environmental depletion and harm to natural and mineral resources. In this research article aggregate is our prime focus of study and its reapplication sustainability in bitumen concrete pavement construction. Talking about Aggregates formation it can either be natural or manufactured. Natural aggregates are generally extracted from quarry extraction in form of rocks. Extracted rock is typically reduced to usable sizes by mechanical crushing as per different sizes required by industries. Manufactured aggregate is often a bye product of other manufacturing industries.

Aggregate is a collective term for the mineral materials such as sand, gravel, and crushed stone that are used with a binding medium such as water, bitumen, Portland cement, lime, etc. to form compound materials such as bituminous concrete and cement concrete.

The coarse aggregates used in road construction should be able to show resistance to crushing under the Roller during construction and adequate resistance to surface abrasion under traffic. The strength of coarse aggregates is assessed by aggregate impact value test and aggregate crushing value test.

Resistance to wear or hardness is another essential property for aggregates used in road construction especially in wearing course.

1.2. Need of Study

Aim: The ultimate aim of this work is to understand the reutilisation of recycled aggregates asa partial replacement of fresh aggregates in bitumen concrete. Also analytically find out the optimal RCA for M30 grade of concrete.

2. LITERATURE REVIEW

The suitability of any aggregate for pavement interlayer is based on certain characteristics. They include the gradation, angularity, soundness and solubility [10]. Typically, recycled aggregates have lower relative densities as well as high water absorption of about 3 to 10%˙. This is due to the presence of mortar surrounding the aggregate and masonry. Also, the presence of micro cracks due to second crushing, collision, and sliding during processing affects these aggregates. Furthermore, Road Construction (RC) have lower crush values and adhesion levels˙. And also subjective to the vertical pressure and number of loading cycle.

Different countries have designed various specification and guidelines for the use of RC in pavement structure. These specifications differ from each other considerably. Different standards use traffic load, field trial, experience, material purity or material properties to classify RC. A lot of work needs to be done to provide a detail workable specifications as most are limited. Developing countries have not written and public their own specification˙ argued that even without a clear specification, the use of RC is viable and cost effective.

The study revealed that recycled aggregates are not always homogenous. They consist of various type of material. RAC might consist of ceramic materials, or bricks. Therefore, a study to examine the effects of various wastes was designed. The use of different processing systems was observed. The results showed that out of the 23 materials tested, 14 met the Spanish regulation of Los Angeles coefficient less than 40. Also, others only failed narrowly. The study also showed that RC had high California Bearing Ratio (CBR) values. The study encourages the use of RA with less than 23% masonry for subbase application. Furthermore, investigation reported that there is no significant variation in compressive strength, flexural strength and split tensile strength of concrete made with RC and NA. However, it stated that there was increase in water absorption as well as reduced modulus of elasticity and resistivity. The author concluded that concrete mixtures needed for pavement construction can use RC but long field performance test should be carried out. In this article author examined the impact of RC (RCA) on asphalt concrete. The investigation revealed that resilient modulus of asphalt containing RC reduced as binder was added. The values obtained with RC were lower than the control. Stripping potential is higher with RC. There are significant variations in strength under moisture conditions. The study recommended a more comprehensive research into various samples or content of RCA as it is viable.

A review by mentioned that several works had been done by through laboratory test. The authors concluded that RC is suitable for pavement interlayer. Ranging from CBR tests, permanent deformation properties, resilient response, degree of compaction, gradation, shear resistance and stability, examined by several researcher from various countries, they all recommended the use of RC in pavement construction. However, the review mentioned that soundness test for recycled materials would not be accurate. It was revealed that cement mortar would adhere to the aggregate which would increase the loss in soundness test.

The author carried out a field trial to test the performance of recycled aggregate to natural aggregates. The study showed that the use of recycled aggregate during construction would demand more water for compaction. However, the result from the dynamic monitoring test showed that the recycled aggregate was better. It concluded that a combination of concrete waste (75%), asphalt (20%) and ceramic material (5%), would provide a satisfactory load-bearing capacity similar to what a natural aggregate would provide. Some reports have stated that recycled aggregate provides more volume than conversional aggregates for the same weight.

The ability of RC to provide the required characteristics necessary for it suitability in pavement construction has being well researched. Depending on the specification for sub-base and base course, different research works have mentioned that it satisfies various specifications and requirements. However, more research into the stress state and permanent strains of RC should be done as asserted by. The durability as well as the aggregate characteristics as regards shrinkage and self-cementing should be examined. Different studies have mentioned that the higher alkali content in RC should be examined. More studies into RC gradation especially fine grains should be done less than 1.18 mm. Also, effects of different pozzolans on RC concrete should be explored.

The next step would be more field trials especially in developing countries. When RC do not meet the specification, stabilization can be carried out to improve the properties of the RC However, attention must be placed on the resilient modulus due to effects of hydration process.

In any typical asphalt pavement, 4-5% of the structure is bitumen. This bitumen portion can be re- laid every 10 to 20 years depending on it performance. The removal is done with a milling machine, then sorted and batched afterward. RAP can be used as the asphalt layer again as part of the asphalt mixture. Asphalt can be recycled 100%.

Wastes such as Fly ash FA, Waste lime, Cement kiln dust (CKD), have been explored as fillers for asphalt mixture. Studies have shown that the inclusion of these and fine RC would have negative impact on asphalt mixture instead improving its engineering characteristics. They are effective and economical. Utilised recycled fine aggregates powder as a filler in asphalt mixture. The study revealed that properties such as water sensitivity, high-temperature properties and fatigue resistance were improved on. Conversely, the low temperature performance decreased.

The research of compared the performance of recycled brick powder and limestone stone filler as asphalt filler. The brick powder was obtained by drying washed brick at 80°C for 10 hours. After which the brick was grounded using a jaw crusher and ball mill for 15 minutes. The study carried out water sensitivity tests, indirect tensile tests, static and dynamic creep tests and fatigue tests. The tests were carried out in accordance to AASHTO T-283, AASHTO TP31 and AASHTO T-321 respectively. Drain down test according to AASHTO T-305 was performed. The material compared had similar properties. However, the recycled brick powder had higher specific surface area and absorption. The study observed that the asphalt with recycled brick filler and concrete aggregate had better indirect tensile modulus, decreased permanent deformation at 60°C as well as improved fatigue life and water sensitive. More research needs to be carried out, as recycled brick powder would varies from place to place.

For recycled aggregate to be used in asphalt mixes, the moisture content must be low. An increase in the moisture content by 1% would require 10% more fuel per tonne. Consequently, several reports have stated that the reduction of the aggregate moisture content by 2%, would save 8.7 kWh and 2.02 kg CO_2 per ton.

The environmental and economic impact of various disposal methods of CDW were evaluated using dynamic model. The study revealed that recycling was the best method. Theoretically, recycling 20% of CDW would reduce the cost over a 20 year period. It concluded by reinforcing the facts that recycling helps to conserve raw materials and landfills space, reduce Greenhouse Gas Emissions (GHG) and costs to mitigate pollution. Author stated that recycling of aggregates requires about 4.0 kg CO_2 per tonne, which is 22 to 46% lower than the convention aggregate. The utilization of 50% RC during in road construction would reduce the embodied energy and GHG emission of material component by 23%. The use of RC helps to reduce GHG emission by 65% while saving 58% non-renewable energy consumption.

3. MATERIALS

The material used in this research article is as follows

A. Portland Pozzolonic Cement (Ultra-Tech Cement): Portland Pozzolonic cement confirming to IS 1489 (Part 2): 1991 is used for testing purpose with specific gravity of 3.15 of ultra-tech cement. The was fresh and without any lumps. Cement was carefully stored to prevent deterioration in its properties due to contact with the moisture.

B. Natural Coarse Aggregate: Two grades of coarse aggregate that is 10 mm and 20 mm are used in present study. Aggregates procured from local vendor and the main source is Yamuna Nagar Quarries

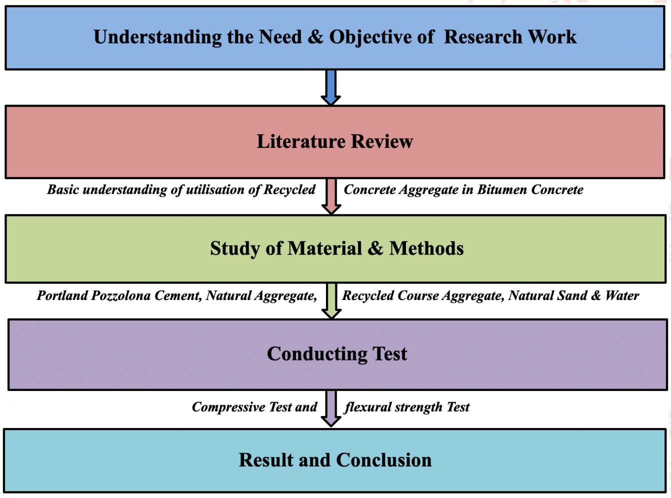
C. Recycled Coarse Aggregate: The aggregate attached with mortar collected from construction site and demolition site to reuse for new construction from Ambala city. The size varies from 4.75 mm to 20 mm in size.

D. Sand: The most important function of the fine aggregate is to assist in producing workability and uniformity in mixture. The fine aggregate assist the cement paste to hold the coarse aggregate particles in suspension. Natural sand from Yamuna river bed is used in this study from local UP river. Depending upon the particle size distribution IS: 383-1970 has divided the fine aggregate into four grading zones (Grade I to IV). The conforming to Grade of used sand is Zone I.

E. Water: Portable tap water is used in this study which is free from salts and other chemicals.

4. METHODOLOGY

This is the section of article which will explains how the research will carried out, from where the data will be collected, the sort of data gathering techniques used, and so forth. Following is the overall methodology shown in flow diagram.



5. TEST AND RESULT

5.1. Compressive Strength

Compressive strength of concrete is one of the most important and useful properties. Concrete is employed primarily to resist compressive stresses. When a plain concrete member is subjected to compression, the failure of the member takes place, in its vertical plane along the diagonal. A flow in the concrete, which is in the form of micro crack along the vertical axis of the member will take place on the application of axial compression load and propagate further due to the lateral tensile strains. The results of the compressive strength tests, as well as the findings of the study will be illustrated in following section.

5.2. Compressive Test

Experimental investigation of fresh mix properties of prepared sample (A to E) was conducted based on IS: 516 – 1959. The compressive strength was measured 7 and 28 day after appropriate curing and specimens were taken for various investigation is as per standard size specified in IS codes that is cube with a 150 mm side in compressive strength testing machine as shown in following future 1.

Fig. 1: Test of Concrete for Compressive Strength

The sample will be tested in compressive strength testing machine to determine compressive strength. The machine receives the 150mm sample size that was casted for the test. The load was applied uniformly and increased gradually at 16 N/mm^2 without causing shock to the sample until the sample's resistance to the growing load was broken. The compressive strength of a particular mix is determined by averaging three cubes across all mixes. Following table shows the compressive strength test results after 7 and 28 days of curing, respectively.

Table 1 Results of Compressive Strength Test on Concrete Cube after 7 Days of Curing

Sr. No.	Mix Design	Wt of cube (kg)	Compressive strength after 7 days (N/mm^2)	
			Individual	Average
1	Mix A (0% RAP)	8.294	29.35	27.32
2		8.147	27.90	
3		8.188	24.71	

4	Mix B (25% RAP)	8.088	25.33	24.21
5		8.070	24.00	
6		7.935	23.32	
7	Mix C (50% RAP)	7.991	14.59	17.42
8		7.843	17.54	
9		8.137	18.89	
10	Mix D (75% RAP)	7.997	13.35	16.95
11		7.771	18.70	
12		8.068	17.80	
13	Mix E (100% RAP)	8.083	17.80	16.35
14		7.946	14.19	
15		8.095	16.88	

Table 2 Results of Compressive Strength Test on Concrete Cube after 28 Days of Curing

Sr. No.	Mix Design	Wt of cube (kg)	Compressive strength after 7 days (N/mm^2)	
			Individual	Average
1	Mix A (0% RAP)	8.338	39.39	38.09
2		8.418	38.29	
3		8.166	37.29	
4	Mix B (25% RAP)	7.886	36.00	35.22
5		7.971	35.44	
6		8.095	35.52	
7	Mix C (50% RAP)	8.073	30.13	31.39
8		7.924	30.23	
9		8.145	33.80	
10	Mix D (75% RAP)	7.845	28.90	28.99
11		7.762	30.19	
12		7.934	28.39	
13	Mix E (100% RAP)	7.926	24.00	25.49
14		7.841	26.19	
15		7.965	27.09	

As demonstrated in Table 3, there is a considerable difference in getting the strength between the average compressive strength of 7 days and 28 days curing. As a general rule, mixing RAP slows the rate of increase in compressive strength when compared to virgin aggregate.

Table 3 Summary of Compressive Strength of Different Mixes after 7 And 28 Days

Sr. no	Mix design	Avg. compressive strength after 7 days curing	Avg. Compressive strength after 28 days curing
1	Mix A (0% RAP)	26.89	39.36
2	Mix B (P)25% RA)	24.09	35.69
3	Mix C (50% RAP)	17.04	31.39
4	Mix (75%)	16.59	29.21
5	Mix E (100% RAP)	16.29	25.81

5.3. Flexure Tensile

Flexural strength is one measure of the tensile strength of concrete. It is a measure of an unreinforced concrete beam to resist failure in bending. In our study beam size 500 mm X 100 mm 100 mm were prepared for testing the flexural strength. The sample's Centre line is precisely aligned with the loading device's Centre line. After properly positioning both the sample and the loading equipment, the load is applied until the sample fails without shock and the severe fibre stress grows at a rate of approximately 7kg/cm^2 per minute. The flexural tensile strength of a sample is the highest tensile load it can bear before breaking.

5.4. Flexure Test

Experimental investigation of fresh mix properties of reinforced concrete was conducted based on IS: 516 – 1959. The Flexural strength of each specimen was determined using IS: 516 -1959. The flexural tensile strengths were measured 7 and 28 day of testing. Following are apparatus and equipment used in the study.

Beam mould of size 15 x 15x 70 cm, when size of aggregate is less than 38 mm and tamping bar which is 40 cm long, approximately weighing 2 kg and tamping section having size of 25 mm x 25 mm.

Fig. 2: i) (Left) Standard size of Beam Mould ii) (Right) Mould applied with oil

Sr. no	Mix design	Avg. Flexure strength after 7 days curing	Avg. Flexure strength after 28 days curing
1	Mix A (0% RAP)	2.15	3.72
2	Mix B (P) 25% RA	2.47	3.6
3	Mix C (50% RAP)	2.19	3.79
4	Mix (75%)	1.98	3.14
5	Mix E (100% RAP)	1.92	3.07

6. CONCLUSION

The study to examine the physical and mechanical properties of RCA used as coarse aggregate in cement concrete was carried out in this research article. Various experiments on aggregates (both virgin and RCA) are carried out in this study to assess their physical and mechanical qualities. The present study was undertaken to investigate the compressive strength and flexure strength of concrete with different level of replacement of recycled aggregate. As per current study carried, the compressive strength of concrete mix (M30) decreases as the percentage of

RAP inclusion increases (after 28 days). It was also discovered that after 28 days, the minimum compressive strength of the RAP aggregate-based concrete mix (M30) is roughly 67 percent that of the fresh concrete mix (M30).

On the other hand flexural tensile strength also shown similar behaviour for the given concrete mix decreases (after 28 days). It was also discovered that after 28 days, the minimum flexural tensile strength of concrete mix (M30) containing recyclable aggregate is decreasing for 28 days.

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