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Recycled Aggregate Concrete: A Critical Review of its Properties, Limitations and Applications

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Abstract: ***Around 1.3 billion tons of solid waste is generated worldwide every year, of which building materials make up roughly 50% of all materials consumed by human activities and similarly contribute to about 50% of the solid waste generated. The waste that is generated during a building construction, maintenance, repair and disposal phase is called Construction and Demolition (C&D) Waste. The management of C&D waste is a big challenge faced by the world. However, rather than being treated as waste, using construction waste as an aggregate for developing new concrete appears to be technically viable. Therefore, the idea of recycled aggregate has been developed and adopted which is beneficial to the environment. The use of RCA in concrete also reduces the demand of virgin aggregates. This paper reports the use of RCA in concrete, its basic properties & also compare the properties of RCA with natural aggregates. Also discuss the production, properties and application of RCA, the barriers to its uptake. The future recommendations are also discussed in addition.***
Keywords: C&D, RAC, NAC, ITZ, compressive strength, modulus of elasticity.

I. INTRODUCTION

The global demand for construction aggregates exceeds 26.8 billion tons per year [1]. The continues industrial development poses severe issue on the construction and the demolition waste disposal. Due to modernization, demolished materials are dumped in land and not used for any other purpose. Such situation leads to the depletion of fertile soil. On the other hand, there is a scarcity of the natural aggregates for the production of new concrete. To solve the problem of "waste" concrete we came up with the idea of recycled aggregate, eventually it also helps in the reduction of environmental deterioration as recycled aggregate is a reliable alternative to natural aggregates.

Recycled Aggregate Concrete is a concrete which is prepared by using recycled aggregates (demolished concrete) as a partial or fully replacement of natural aggregate. Recycled aggregates are generally obtained by crushing and processing concrete rubble and burnt clay brick masonry construction. The use of RA started since the end of World War II by using a demolished concrete pavement as recycled aggregate in stabilizing the base course for road construction [2],[3] The only difference between recycled aggregate and natural aggregate is the adhered cement mortar that is attached to the NA present at the core. The fraction of adhered mortar (by volume of the sample) decreases with increase in the nominal size of the aggregate. The sustainability of RCA lies in its ability to reduce landfill waste, preserve natural resources and environmental degradation.

Recycled aggregate is made up of crushed, grained inorganic processed particles from the materials that are used in construction work and demolition debris. The structure of the demolished material and the method of production will decide the RAC category. As the recycled aggregates were made from destroyed structures, they consist of old mortar which is porous and used for low-level applications. From studies, it was found that the increase in the proportion of RA in concrete mix will leads to decrease in the properties of RAC such as compressive strength and flexural strength. So, to enhances performance of RAC pozzolanic materials such as silica fume and fly ash are commonly added [8],[25]. When we talk about its application RAC is mainly used in base layer, pavement, sidewalks etc. which we will discuss in this paper.

A. Objective

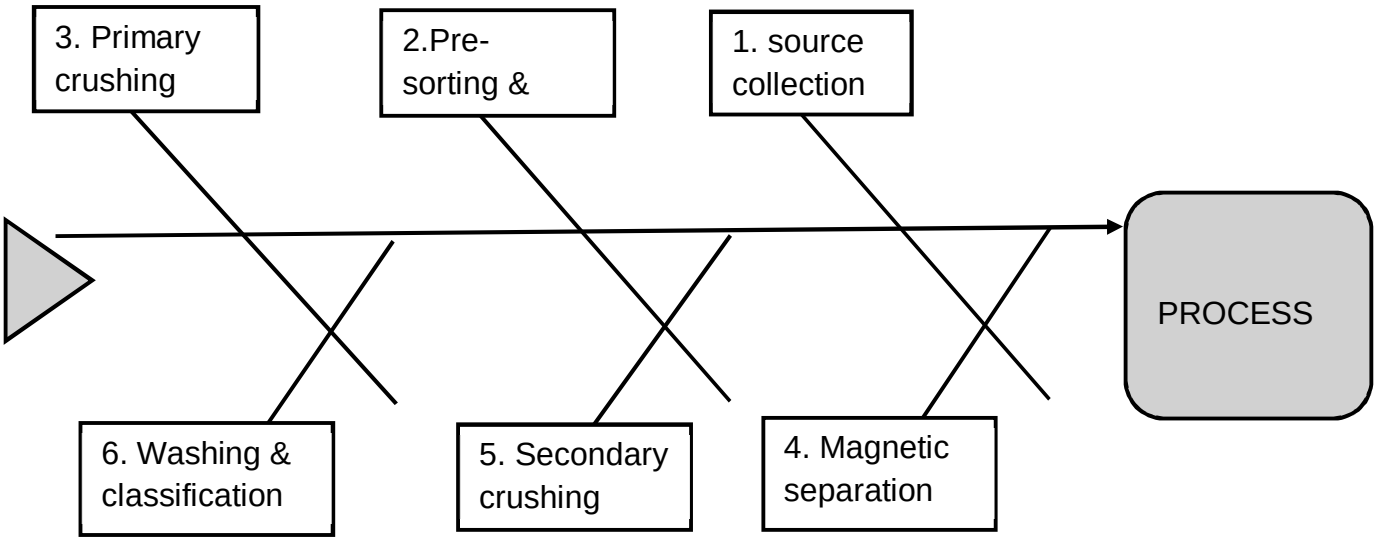
- To study the use of recycled aggregate as an alternative to natural aggregate.
- To examine the different properties of recycled aggregate concrete.
- To study the source and the material used for the production of RA.
- To assess its environmental and economic benefits.
- To compare the recycled aggregate concrete with natural aggregate concrete.
- To identify its applications in construction and its limitations.

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II. SOURCES AND PRODUCTION OF RECYCLED AGGREGATE:

Waste concrete from tested cube and cylinder samples and various demolished structures like pavement, bridges, foundations, brick and masonry waste or buildings were collected and taken to a crusher unit nearby and crushed into various sizes [4]. During processing, unwanted contaminants like wood, plastic, metals & glass etc. are removed. After screening, the materials were separated into the size of course aggregate required for the replacement of natural aggregate in concrete. It should be taken into consideration that the recycled aggregates shall be stored separate from the other type of aggregates and transported in a manner to prevent breakage and segregation otherwise it will lead to the changes in the quality of the RA.



III. PROPERTIES OF RECYCLED AGGREGATE

The basic properties of recycled aggregates may significantly differ from the properties of natural aggregates. The difference in properties mainly depends upon the quality and quantity of the cement mortar, which is attached to the grain of recycled aggregate [1]. Then, also on the quality of the original concrete from which the aggregate is made by recycling and the method of recycling.

A. Particle size distribution

The result of sieve analysis carried out as per IS 2368 for different types of recycled concrete aggregate and natural aggregates. It is found that the recycled coarse aggregates are reduce to various sizes during sieving and crushing which normally satisfies the standards for natural aggregates [4]. However, in case of fine recycled aggregate, composition corrections are often necessary because it was found that there was often a certain number of grains larger than what is required by standards for natural aggregate [5]. The particle shape analysis of recycled concrete aggregate indicates a similar particle shape of natural aggregates obtained from a crushed rock.

B. Water Absorption

Water absorption of recycled aggregate is one of the most significant properties that distinguish recycled aggregate from raw aggregate. According to the researches, it has been found that recycled concrete aggregate has a significantly higher level of absorption compared to natural aggregate [4],[5],[7].[9]. The reason behind this, is the original cement mortar, which is an internal part of the recycled aggregate and has more porous structure compared to natural aggregate. However, the porosity mainly depends upon the water- cement ratio of original concrete.

C. Bulk Density

Recycled aggregate has a lower value of bulk density than the bulk density of natural aggregate due to the higher porosity of mortar layer. The mutual difference between them decreases if the recycling is conducted by an advanced technology, which remove a significant portion of old cement mortar. According to practical experience, it was found that the bulk density of recycled aggregate was on the average by 10% lower compared to the bulk density of natural aggregate [5],

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D. Impact Value & Crushing Value

The crushing and abrasion value of recycled aggregates is greater than the respective values of natural aggregates [4],[5],[27]. The mechanical properties of recycled aggregates mainly depend upon the quality of cement mortar present in recycled aggregates and in the case of natural aggregate it depends on the factors like the type of original aggregate, shape, size of grain and grading of the aggregates.

As per IS 2386 part (IV), the crushing and impact values for concrete wearing surfaces should not exceed 30% & for other than wearing surfaces 45% respectively. The crushing & impact values of recycled aggregate satisfy the BIS specifications limit [4].

Table 1 Comparison between different properties of RA and NA [6]

Sr. no.	Properties	RAC	NAC
1.	Water absorption	4.115%	1.755%
2.	Bulk density	1292 kg/m^3	1481 kg/m^3
3.	Fineness Modulus	2.319%	2.293%
4.	Impact value	37.92%	13.04%
5.	Crushing Value	26.23%	16.71%
6.	Specific Gravity	2.450	2.819

IV. LITERATURE REVIEW

Ashraf M. Wagih et al (2013) [1]: In this research paper, the objective was to know about the possibility of replacement of natural aggregate with recycled aggregate in structural concrete. For that they used crushed and graded concrete rubble collected from different demolition sites and landfill locations around Cario. To investigate the effects on properties of concrete, they used three different types of aggregate (natural aggregate, dolomite & crushed concrete) in concrete mix. Fifty concrete mixes forming eight groups were casted to study the effect of RA
content, cement content, superplasticizers dosage. Mainly tests were carried out for compressive strength, elasticity modulus and splitting strength. The results showed that the RA could be used in concrete production but there was also noted that the concrete made with 100% of RA have less value of mechanical properties as compared to NA.

Akash Rao, Kumar N. Jha et al (2007) [2]: This paper discussed about the rising problem of C&D waste generation and its disposal. The problem can be solved using recycled aggregates made from these C&D waste. Also, discuss that the RA made from C&D waste can be contaminated with salts, plastic, sand, paper and metals. They studied about the effect of use of RA on fresh and harden concrete properties. As the result from the study, it was concluded that use of RA in concrete could be a better solution to the C&D waste, also it found that RA can be used in lower end applications of concrete.

N. Kisku., H. Joshi et al (2017) [3]: The study focused on the need of sustainable construction material as the construction industry is the sector with most environmental impact as it consumes large amount of energy, natural resources and generate enormous amount of waste. They started using aggregates made with these construction waste, investigates its fresh state and mechanical properties. The study found that the mechanical properties were responsible for the performance of RAC under different climatic conditions. The paper also studies about the microstructure of RA and stated that the RA consists of adhered mortar from the old cement matrix and leads to the formation of two Interfacial Transition Zones (ITZ).

Tushar R Sonawane et al (2013) [4]: In this paper, the basic properties of RA and RAC were studied and comparing these properties of RAC with NAC. For this test were conducted using RA from demolished materials of RCC & PCC. The crushing, sieving and separation of demolished materials are done manually by crushing method. The tests conducted on RA were carried out as per Indian Standard Code for natural aggregate and checking feasibility. The result findings showed that use of RA up to 30% does not affect the structural requirements of the structure.

Mirjana Malešev et al (2014) [5]: The paper also discussed the different properties of recycled aggregates and RAC and its application in construction. The paper stated that the compressive strength of RAC depends on the quality of recycled aggregate and found that the compressive strength values of RAC is lower than compare to the NAC. Tensile strength of concrete is determined by split tensile test and generally does not depend upon the amount of RA used, further showed a relationship graph between compressive strength and tensile strength.

Yati R. et al (2014) [6]: The main aim of this paper is to develop an economical and sustainable concrete using concrete waste materials available on sites. The use of RAC will help to save energy and natural resources for future. To obtain a specified strength of RAC tests were carried out.

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The experiment used OPC 53 grade concrete, the fraction of fine aggregate used are 4.75mm to 150 micron and 20mm to 4.75mm for coarse aggregates. The C&D waste was collected from a demolished building name "Shree Ram Hospital". Potable water was used for preparing M25 grade concrete and a superplasticizer named FAIRFLO-333 was used. For the experiment various concrete mix batches were prepared with 0%, 20%, 40% & 60% replacement of RA with NA. The paper generally works on compressive strength and workability parameter. The result found out that there is a sudden decrease in the strength at 40% and 60% replacement.

V. Radonjanin et al (2013) [8]: The paper represents the experimental result of concrete made with recycled aggregate, low cement content and high content of different mineral supplements. Such type of concrete is called 'green' concrete since they have low impact on environment and use less quantity of natural resources. For preparing green concrete fine river aggregate, coarse recycled aggregates were used and 50% of cement by weight was replaced with different pozzolanic, inert and highly reactive mineral admixtures. Basic properties of 10 different concrete samples were tested and result showed that the optimal combination of different mineral admixtures can help to reduce the disadvantage of concrete with high content of mineral supplements.

Prajapati, Rohit & Amadi (2013) [9]: In this paper the authors discussed the need for the C&D waste management and how the recycled aggregate could now become a possible solution to this problem. The paper provides the knowledge how the C&D waste can be recycled and the production method of RA along with its properties and their comparison with natural aggregates. They also reviewed about the life cycle assessment of concrete which is standardized methodology used for the calculation of environmental impacts. This life cycle analysis showed that there is a negligible change in the energy consumed and CO_2 emission related to the production of recycled aggregates.

V. APPLICATION OF RAC

1) Recycled aggregate is commonly used as a partial or fully replacement of natural aggregate which reduces our dependency on natural available aggregates and also uses to reduce the waste generated through demolish structures.
2) Recycled aggregate concrete can also be used in the construction of pavement used as a subbase layer [9],[27]. The structural requirement of the top layer to transmit vehicular load limits the use of RAC for rigid pavement.
3) RAC can also be used in the construction of beams, slabs, foundation, precast concrete, retaining walls, drainage structures, sidewalks, backfill by enhancing the some of the properties of RAC [24],[28].
4) Finely crushed recycled aggregate concrete powder is used as a filer material for the preparation of highly fluid called self-compacting concrete.

VI. LIMITATIONS AND CHALLENGES

1) High water absorption of RAC is the major challenges faced during the preparation of concrete mix. RAC contains old adhered mortar which causes it to absorb more water as compared to the natural aggregates. The highwater absorption of recycled aggregate will eventually lead to the increase in workability which results in lowering the strength of the concrete. To avoid these problems proper w/c ratio is used and make use of superplasticizers to reduce the absorption of water.
2) As we studied above that the compressive strength of RAC is lower than the natural aggregate concrete. It mainly depends upon the quality and percentage of RA used in the mix. High percentage of RAC (above 30%) can lead to lower the compressive strength, reduced the density and lower the modulus of elasticity of the recycled aggregate concrete [22].
3) The material used as recycled aggregate has inconsistent source which increases the variability of the material. The different source material from C&D waste have varying particle shapes, moisture content, porosity and grading all these will eventually leads in the variation of the properties of recycled aggregate.
4) The transportation cost of demolition structure from the site to the processing plant and the cost of processing of C&D waste will make the RAC more expensive than natural aggregate in region with cheap local quarries [9],[28].
5) The RAC if frequently used in the low- value applications like road subbase rather than structural concrete due to its limitations in the value of compressive strength and other mechanical properties.

VII. DISCUSSSION

From the reviewed studies, it can be identified that the recycled can be used as a possible alternative to the natural aggregates. Researchers found that the use of recycled aggregate can solve the problem of disposal of C&D waste and also reduce the demand of natural resources. The study helps to know the different materials and steps involved in the production of RA. The researchers observed that the properties of RCA depend on the quality and the percentage of RA used in the concrete mix.

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They conducted experiments with different proportion of RA in concrete mix to identify their effects on the properties of concrete. They found that the RA has greater water absorption value than the NA and due to which has lower strength value. But further study shows that with correct percentage of RA and admixtures in the mix can help to achieve the concrete of desired strength. Therefore, RAC can lead to more sustainable construction practices. However, some limitations were also seen with the use of RAC. Thus, more research is still required to develop better methods for production and to study long-term durability of RAC under different conditions.

VIII. CONCLUSION

From the studies of different properties of recycled aggregate concrete, we will come up with following conclusions:

1) RAC is useful as a substitute to natural aggregates to produce concrete with desirable properties under specifications. The only problem with the RAC is its inconsistent quality when it is obtained from old mortar.

2) The physical properties of RAC significantly influence the fresh and hardened state properties of concrete. The aggregate abrasion, crushing and impact value of RAC affects the compressive strength, stiffness, tensile strength values of concrete.

3) However, the effects can be reduced by using accurate characterization of RAC, moisture control, pre- treatment, proper mixing procedures etc.

4) The use of 100% RAC is possible to produce concrete with acceptable quality. The concrete made with RAC has 80 – 90% of the compressive strength compared to concrete made with natural aggregates. The reduction in the strength is caused by the adverse physical properties of RAC.

5) The use of fine RAC in production of new concrete is examined carefully, as the fine RA will reduce the strength of concrete. In general, it was found to be 10% reduction in strength of concrete made from RAC as compared to natural aggregates.

6) The performance of RAC can be enhanced by adjusting water-cement ratio, use of pozzolanic materials and admixtures.

7) RAC can be used as high-quality concrete such as high strength, high performance and self- compacting concrete by appropriate material selection and mix design.

The environmental potential of RAC is considered because it helps in the reduction of waste that being dumped on landfills causing the shortage of land for other purposes and reduction in the consumption of natural aggregates. The future of RAC not only depends on the research to increase the percentage of RAC but also on producing high-quality RAC and designing concrete around its characteristics.

IX. FUTURE SCOPE

Further, the research is needed in the long-term performance of RAC, to study durability different environmental conditions, high replacement ratios, standard quality control, combined treatment techniques and reliable life cycle assessment.

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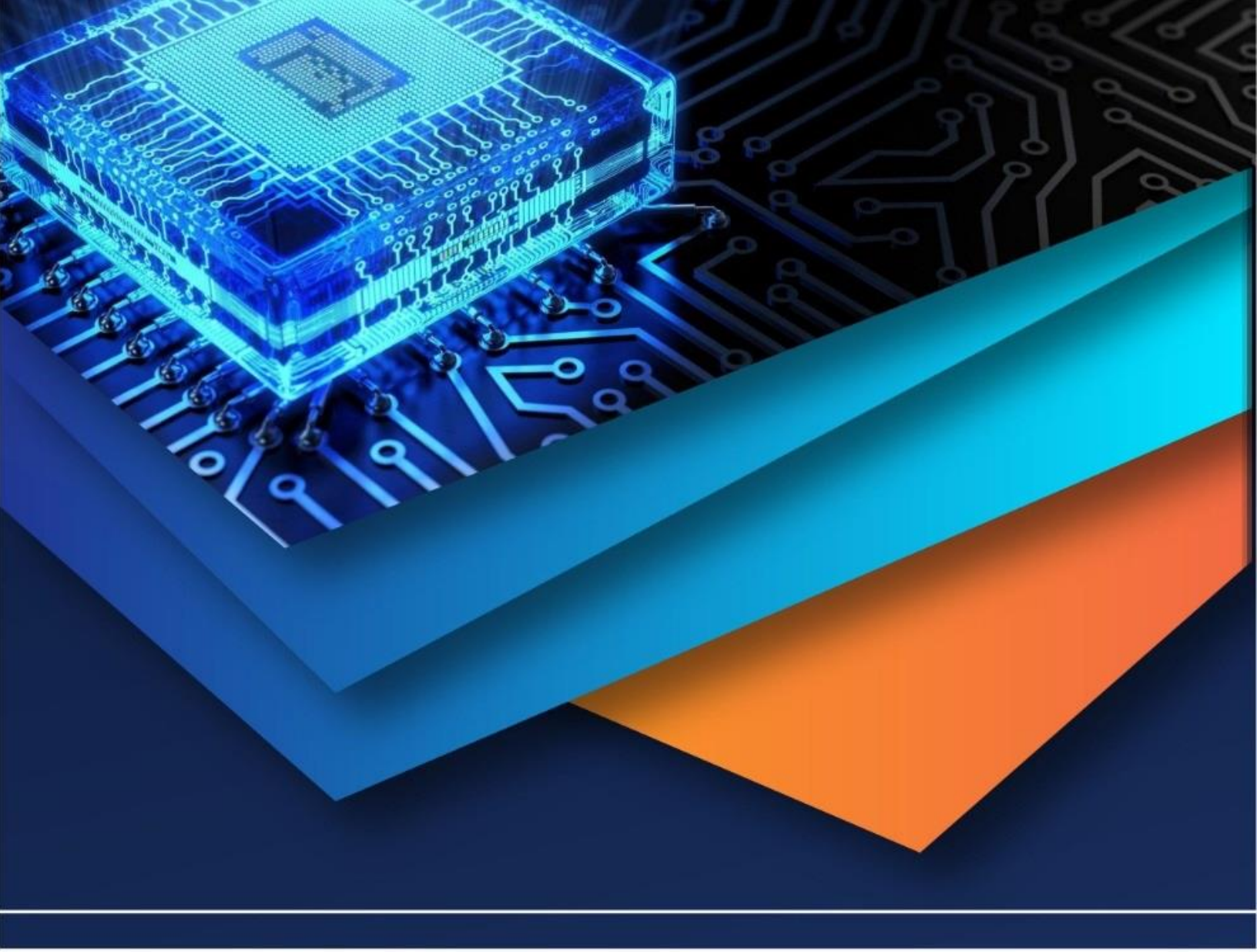
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