Carbonation of Concrete and the Use of Recycled Aggregates to Reduce Carbonation

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Abstract- Concrete is naturally carbonated when calcium hydroxide (Ca(OH)2) in the cement paste combines with carbon dioxide (CO2) from the air. Concrete's pH is lowered as a result of this reaction, which over time can cause it to lose strength and durability. Concrete that contains recycled aggregates may help lessen the effects of carbonation. Recycled aggregates can be used in place of natural aggregates in new concrete mixtures and are produced through the demolition of existing concrete buildings. In order to reduce carbonation in concrete, this study describes experimental testing on the usage of recycled aggregates. According to the test findings, recycled aggregates can be used to lessen concrete's carbonation.

Keywords:Carbonation;Recycled aggregates;durability;pH

1.Introduction

One of the most popular building materials in the world is concrete, but a number of things, including carbonation, can eventually reduce its durability. When the calcium hydroxide (Ca(OH)2) in the cement paste combines with carbon dioxide (CO2) from the air, carbonation, a natural process, results. Over time, this reaction can cause the concrete's strength and durability to decline as it lowers the pH of the material.

The majority of buildings and structures continue to be at considerable danger from fire, and there are a few things that can be done to reduce this risk[21]. When admixtures are added to concrete, its strength and durability improves with different mix amounts have been tested[22,23].The strength criteria are also altered when cement is replaced in concrete[24,25].Also, addition of the alccofine in the concrete gain strength was been observed in the concrete[26].

Concrete is vulnerable to chemical attacks and deterioration despite its great strength and capacity to withstand the movement of water. Durability refers to a concrete's ability to withstand chemical assaults, weathering effects, abrasion, or any other type of deterioration throughout the course of its service life under a certain set of circumstances. Concrete's strength and durability are influenced by the characteristics of its constituent parts, the design mix's proportions, the environment it is exposed to, and the kind and length of curing. Concrete's durability is affected by both chemical and physical factors. Surface wear and cracks are the two main physical causes of concrete degradation. The cracking is caused by a change in volume, structural stress, and exposure, whereas the surface wear is caused by abrasion, erosion, and cavitation..Sesimic behaviour of the concrete can be observed in the concrete and also if need addition of the several material can be done to increase its strength and durability[27].

Calcium (Ca2+) ions from the cement and carbonate (CO3-) ions from the dissolved carbon dioxide (CO2) react during the carbonation of concrete to precipitate calcium carbonate (CaCO3). When the design mix proportion standards are not reached, concrete has some porosity. Additionally, concrete surfaces degrade with time when exposed to atmospheric fluids, and occasionally this deterioration is accelerated by the capillary holes that link the surfaces. With the addition of the geopolymers to the admixture, the concrete was found to gain strength and durability quickly[29].

Utilising recycled aggregates in concrete is one possible method to mitigate the effects of carbonation. Old concrete buildings can be demolished to provide recycled aggregates, which can be used in place of natural aggregates in fresh concrete mixtures. This strategy may not only save the carbon footprint of making concrete, but also increase the concrete's longevity. Pretreating RCA by the Ca^{2+} rich wastewater could further enhance the effects of the flow-through carbonation for RCA[3]. Many research papers have examined the use of recycled aggregates in concrete in recent years, with many of them concentrating on how recycled aggregates affect carbonation. Experimental analysis was performed on the concrete to observe its strength and durability[28].

The use of recycled aggregates in order to reduce carbonation in concrete has been tested experimentally, as shown in this research. The purpose of the testing was to evaluate the effects of recycled aggregates on the carbonation process and the durability of the concrete that resulted. The treatment techniques proposed can be a powerful tool for promoting the use of RA in the construction industry[1]. The findings of the studies show that recycled aggregates have the potential to reduce concrete carbonation while increasing its durability, giving them a promising option for long-lasting and environmentally friendly construction. There were five kinds of CO2 diffusion paths in recycled aggregate concrete and their carbonation depths showed a noteworthy difference[2].

The CO2 uptake by RCAs is remarkable and reaches 35.8%–64.3% of the total CO2 uptake by RAC when the RCA storage time being 30 days[6]. The mean carbonation depth in concretes with 25% recycled aggregate is 1.07 times greater and in materials with 50% replacement 1.18 times greater than in conventional concretes with natural aggregates[8].

2.Materials&Methodology:

Materials:

Materials that have been used in building earlier and then processed once again for use in new construction projects are referred to as recycled aggregates. Various materials, such as reclaimed concrete, ancient bridges, and demolished structures are possible sources for these aggregates.

Recycled aggregates may be used in place of natural aggregates like gravel and sand to generate fresh concrete, which is applicable to the construction industry. By lowering the quantity of trash that is dumped in landfills and by preserving natural resources, using recycled aggregates can assist in minimising the environmental effect of construction.

Overall, using recycled aggregates in concrete may be a viable and economical choice for building projects, but careful planning and management are needed to make sure it is successful.

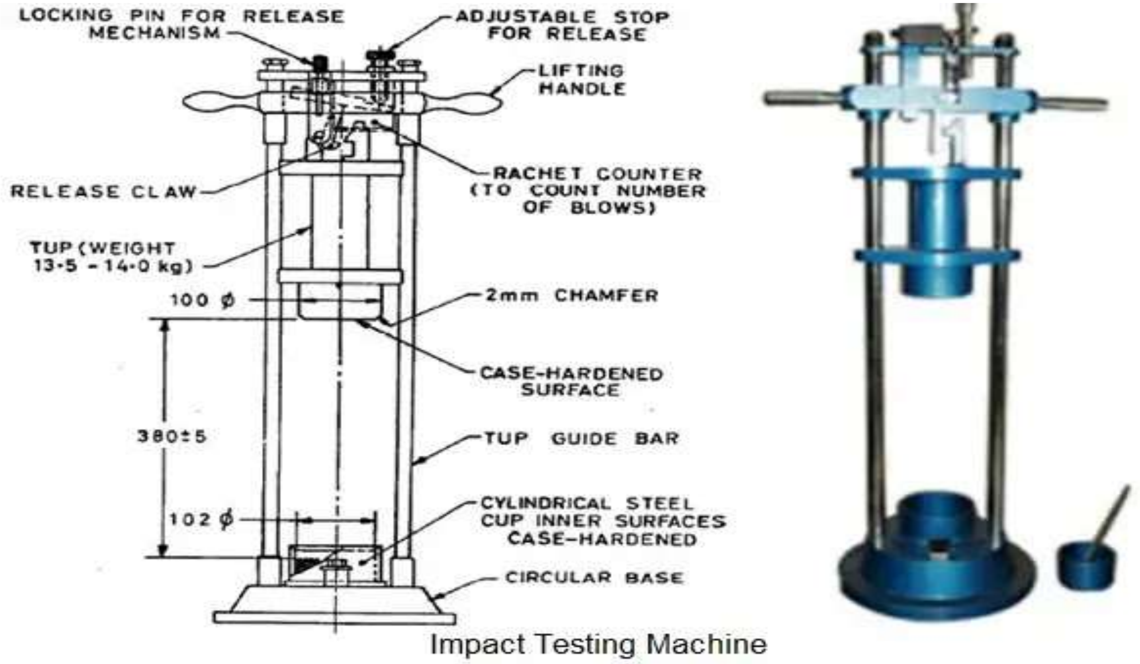
Tests:

When employing recycled aggregates in concrete, it's crucial to carry out a variety of tests to make sure the finished product will adhere to the standards and function as intended. testing for compressive strength, accelerated carbonation, SEM-BSE, density, and chloride ion penetration may all be performed on recycled aggregates in concrete. Other important testing include water absorption and aggregate impact value tests.

1.Aggregate Impact value test:

The aggregate impact value (AIV) test evaluates an aggregate's resistance to shock or impact. The AIV test is frequently used to assess an aggregate's appropriateness for use in road construction since it may show if the aggregate can survive traffic loads and other types of impact.

The AIV test may be used to evaluate the material's quality and toughness when it comes to recycled aggregates. The AIV test is carried out in the same manner as it would be for natural aggregates: a sample of the material is struck with a metal hammer, and the amount of fragments broken down are counted.



Photographs of impact testing machine with its sketch

2.Water absorption test:

A typical test used to evaluate the capacity of recycled aggregates to absorb water is the water absorption test. This test is crucial because the aggregate's capacity to absorb water can have an impact on the final concrete's qualities, including workability, strength, and durability.

A sample of the recycled aggregate is weighed before being placed in a container of water for a predetermined amount of time to perform the water absorption test. Following the aggregate's removal from the water, the surface water is delicately wiped away with a moist cloth before the aggregate is once more weighed.

Calculating the amount of water absorbed by the recycled aggregate involves comparing the weights of the dry and wet aggregates. This is represented as a percentage of the aggregate's dry weight. The recycled aggregate's porosity and the amount of contaminants contained in the material may both be determined by the water absorption test. High water absorption recycled aggregates may be more porous and contain more pollutants, which might lower the quality of the concrete that is produced.

3.Particle size distribution test:

To ascertain how the distribution of particle sizes in the material is distributed, recycled aggregates are frequently subjected to the particle size distribution (PSD) test. The PSD test is significant because it has the potential to change the final concrete's characteristics, including its workability, strength, and durability.

A sample of the recycled aggregate is first dried in an oven to eliminate any moisture before performing the PSD test. The dried sample is next divided into various size fractions using a series of sieves with varied mesh diameters.

Using a mechanical shaker or by manual filtering, the sample is put on the top sieve and shaken for a predetermined amount of time. Each sieve's retention of material is weighed, and the proportion of that material that passes through each sieve is computed.

The proportion of material passing through each sieve size can be displayed in a graph or table along with the PSD test results. The strength and workability of the final concrete may be impacted by the recycled aggregate's grading, which may be determined by the PSD test. Compared to materials that are not properly graded, recycled aggregates with a well-graded particle size distribution can assist generate concrete that is more workable and stronger.

Fig: Sieve analysis

4.Density test:

A typical test used to measure the bulk density and unit weight of recycled aggregates is the density test. This test is crucial because the density of the aggregate can impact the workability, strength, and durability of the final concrete.

A known volume of the recycled aggregate is first measured using a container of known capacity, such as a cylinder or box, in order to conduct the density test. The bulk density and unit weight of the material are then computed after weighing the aggregate on a scale to ascertain its weight. Unit weight is the weight of the aggregate per unit of volume, excluding the voids, whereas bulk density is the weight of the aggregate divided by the entire volume it fills. The density test may be used to measure the porosity and compactness of the recycled aggregate, which can have an impact on the final concrete's quality.

Recycled aggregates with high bulk density and low porosity are generally preferred for concrete production because they can lead to concrete with improved strength and durability.

Fig:Density Test

5.Compressive strength test:

An essential test used to evaluate the strength of concrete built using recycled aggregates is the compressive strength test. This test is significant because concrete's compressive strength plays a significant role in evaluating whether it can be used for a variety of building applications. Concrete mixtures including recycled aggregates are used to cast cylindrical or cubical specimens for the compressive strength test. The specimens are then allowed to cure for a certain amount of time—usually 28 days—under carefully monitored circumstances. The specimens are loaded until they break in a compressive testing machine after the curing time. The specimen's failure load is noted, and the concrete's compressive strength is estimated using the specimen's cross-sectional area.

The compressive strength test can be used to assess if recycled aggregates are suitable for use in the creation of concrete. Concrete with increased strength and durability may be produced using recycled aggregates with strong compressive strength. Based on the compressive strength and w/c ratio, it is possible to estimate the amount of substitution of natural aggregate needed in concretes for an expected elastic modulus[14].

Fig: Compressive strength test

6.Chloride ion penetration test:

The resistance of concrete built with recycled aggregates to chloride ion penetration is usually assessed using the chloride ion penetration test. Concrete's steel reinforcing can corrode due to chloride ion penetration, which can result in structural damage and less durability. Concrete specimens constructed with recycled aggregates are first cured under strict supervision for a certain amount of time, usually 28 days, in order to conduct the chloride ion penetration test. The specimens are then kept in a chloride-ion solution under predetermined conditions—such as temperature and humidity—for a certain amount of time.

The specimens are divided along a plane parallel to the surface after the exposure time, and the depth of chloride penetration is then determined using a variety of techniques, including visual examination, chemical analysis, and electrical resistivity testing. The findings of the chloride ion penetration test may be used to estimate how chloride ion resistant the concrete constructed using recycled aggregates is. Increased water absorption and impurity levels in recycled aggregates can result in concrete that is less resistant to chloride ion penetration, which can diminish durability and increase the risk of structural damage.

7.SEM-BSE Analysis:

SEM, a powerful analytical method for examining the microstructure of materials, is employed in research. SEM may be used to analyse the interfacial transition zone (ITZ) between the cement paste and the recycled aggregates in concrete with recycled aggregates. Cement paste and recycled aggregates, for example, can be distinguished from one another via backscattered electron (BSE) imaging, a form of SEM imaging. The ITZ—an critical zone that can impact the strength and longevity of the concrete—between the cement paste and the recycled aggregates can be identified with the use of BSE imaging.

Images that arise from this process can provide important details regarding the microstructure of recycled aggregate concrete, such as the size, shape, and distribution of the recycled aggregates, as well as the effectiveness of the ITZ between the cement paste and the recycled aggregates.

8.Accelerated carbonation test:

An experiment known as the "accelerated carbonation test" is conducted in laboratories to resemble the gradual carbonation of concrete that naturally takes place. When calcium hydroxide (Ca(OH)2) in cement paste combines with atmospheric carbon dioxide (CO2) to generate calcium carbonate (CaCO3), the process is known as carbonation. The accelerated carbonation test can be used to assess the concrete's resistance to carbonation in cases when it contains recycled aggregate. Concrete's strength and durability can be impacted by carbonation, and using recycled aggregates that are less reliable or have greater impurity levels can result in concrete that is less resistant to carbonation.

Cylindrical or cubical specimens are initially cast using the concrete mix including recycled aggregates in order to conduct the accelerated carbonation test on recycled aggregate concrete. The specimens are then allowed to cure for a certain amount of time—usually 28 days—under carefully monitored circumstances. Following the curing process, the specimens are put in an accelerated carbonation chamber and subjected for a predetermined amount of time to a high CO2 concentration, along with regulated humidity and temperature. The findings of the accelerated carbonation test may be used to gauge how well the recycled aggregate concrete resists carbonation. Longer service life and increased durability are possible benefits of concrete with strong carbonation resistance. CO2-curing treatment improves RA property, and there is an obvious reduction in water absorption of CRA[4,5].

Accelerated carbonation is regarded as an efficient and economical way to improve the mechanical properties of recycled concrete aggregates (RCAs) through strengthening the attached mortar/cement paste[7].

Results&discussion:

Water absorption: This test determines how much water the recycled aggregate can hold. The findings may be used to assess the aggregate's porosity and permeability as well as the likelihood of moisture-related issues including freeze-thaw damage. Generally speaking, recycled aggregates absorb more water than native aggregates.

The CO2-curing procedure enhances the properties of RA, and a noticeable decrease in water absorption was noticed. Stronger than RA concrete is CRA concrete. The alkalinity of CRA concrete is, however, lower than that of RA concrete since CRA pH is lower than RA pH. The inclusion of metakaolin (MK) as a mineral admixture has been found to compensate the loss in the carbonation resistance on account of substitution of NA with RCA to some extent[10].

Concrete's carbonation depth is reduced when RA gets replaced with CRA; the maximum carbonation depth of C-CRCA + CRFA is around 42.5% lower than that of C-RCA + RFA. The mixtures with 50% RA and 100% CRA exhibit comparable durability for all characteristics under examination. Steel Fiber Reinforced Recycled Aggregate Concrete has good durability and can be successfully applied to structural members with proper mixture design[9].

With losses under 12% and a loss of 51% in carbonation, it appears that the mix with 25% RA performs the best. Carbonation treatment has been shown to densify the microstructure and lessen water absorption in cement pastes and RCAs.

Through its method for carbon capture, accelerated carbonation treatment is a possible ecologically beneficial treatment[11]. The highest results were obtained under accelerated carbonation treatment, which increased the AIV and WA by 11% and 46%, respectively, at 50% CO2 concentration for six days.

In terms of compressive strength, density, water absorption, sorptivity, and resistance to Cl ion penetration, the concrete made with the wastewater-treated and carbonated RCA outperformed the conventional RAC.

Conclusion:

There are possible advantages and disadvantages of using recycled aggregates in concrete. Positively, by lowering the demand for new materials and waste, the use of recycled aggregates may reduce the environmental effect of the manufacture of concrete. Additionally, it might increase the building sector's sustainability. However, the performance and characteristics of the concrete might potentially suffer from the usage of recycled particles. The workability and strength of the concrete may be impacted by recycled aggregates' increased water absorption and reduced density when compared to native aggregates. Recycled aggregates could also contain impurities like leftover mortar or other compounds that impair concrete's durability and functionality.

The best increase in the characteristics of concrete and good resistance to carbonation have been seen with replacement of 25% RA.Overall, using recycled aggregates as a substitute material may increase a building's durability and sustainability as well as lowering its cost.

References:

1. Al-Waked, Q., Bai, J., Kinuthia, J., Davies, P.(2022). Enhancing the aggregate impact value and water absorption of demolition waste coarse aggregates with various treatment methods.
2. Mi, R., Liew, K.M., Pan, G.(2022). New insights into diffusion and reaction of CO2 gas in recycled aggregate concrete.
3. Fang, X., Zhan, B., Poon, C.S.(2021). Enhancement of recycled aggregates and concrete by combined treatment of spraying Ca2+ rich wastewater and flow-through carbonation.
4. Liang, C., Lu, N., Ma, H., Ma, Z., Duan, Z.(2020). Carbonation behaviour of recycled concrete with CO2-curing recycled aggregate under various environments.
5. Park, J., Lee, J., Chung, C.-W., Wang, S., Lee, M.(2020). Accelerated carbonation of recycled aggregates using the pressurized supercritical carbon dioxide sparging process.
6. Huang, K., Li, A., Xia, B., Ding, T.(2020). Prediction on CO2 uptake of recycled aggregate concrete.
7. Fang, X., Zhan, B., Poon, C.S.(2020). Enhancing the accelerated carbonation of recycled concrete aggregates by using reclaimed wastewater from concrete batching plants.
8. Saez del Bosque, I.F., Van den Heede, P., De Belie, N., Sánchez de Rojas, M.I., Medina, C.(2020). Carbonation of concrete with construction and demolition waste based recycled aggregates and cement with recycled content.
9. Gao, D., Zhang, L., Zhao, J., You, P.(2020). Durability of steel fibre-reinforced recycled coarse aggregate concrete.

10. Singh, N., Singh, S.P.(2016). Carbonation resistance and microstructural analysis of Low and High Volume Fly Ash Self Compacting Concrete containing Recycled Concrete Aggregates.
11. Torrenti et al.(2022). The FastCarb project: Taking advantage of the accelerated carbonation of recycled concrete aggregates.
12. Gong, Y., Chen, P., Lin, Y., Wan, Y., Zhang, L., Meng, T.(2022). Improvement of recycled aggregate properties through a combined method of mechanical grinding and microbial-induced carbonate precipitation.
13. Russo, N., Lollini, F.(2022). Effect of carbonated recycled coarse aggregates on the mechanical and durability properties of concrete.
14. da Silva, S.R., Cimadon, F.N., Borges, P.M., Schiavon, J.Z., Possan, E., Andrade, J.J.D.O.(2022). Relationship between the mechanical properties and carbonation of concretes with construction and demolition waste.
15. Wu, K., Luo, S., Zheng, J., Yan, J., Xiao, J.(2022). Influence of carbonation treatment on the properties of multiple interface transition zones and recycled aggregate concrete.
16. Wu, J., Ding, Y., Xu, P., Zhang, M., Guo, M., Guo, S.(2022). uniaxial compressive stress-strain behaviour of recycled aggregate concrete prepared with carbonated recycled concrete aggregates.
17. Mahmood, W., Khan, A.-U.-R., Ayub, T.(2022). Carbonation Resistance in Ordinary Portland Cement Concrete with and without Recycled Coarse Aggregate in Natural and Simulated Environment.
18. Liu, H., Hua, M., Zhu, P., Chen, C., Wang, X., Qian, Z., Dong, Y.(2021). Effect of freeze–thaw cycles on carbonation behaviour of three generations of repeatedly recycled aggregate concrete.
19. Singh, M., Danie Roy, A.B., Waseem, S., Singh, H.(2021). Feasibility and performance analysis of carbonated recycled aggregate concrete.
20. Saez del Bosque, I.F., Van den Heede, P., De Belie, N., Sánchez de Rojas, M.I., Medina, C.(2020). Carbonation of concrete with construction and demolition waste based recycled aggregates and cement with recycled content.
21. Sathi, Kranthi Vijaya, Sudhir Vummadisetti, and Srinivas Karri. "Effect of high temperatures on the behaviour of RCC columns in compression." Materials Today: Proceedings 60 (2022): 481-487.
22. Srinivas, Karri, Sathi Kranthi Vijaya, Kalla Jagadeeswari, and Shaik Lal Mohiddin. "Assessment of young's modulus of alkali activated ground granulated blast-furnace slag based geopolymer concrete with different mix proportions." (2021).
23. Srinivas, Karri, M. Padmakar, B. Barhmaiah, and Sathi Kranthi Vijaya. "Effect of alkaline activators on strength properties of metakaolin and fly ash based geo polymer concrete." JCR 7, no. 13 (2020): 2194-2204.

24. Vijaya, Sathi Kranthi, Kalla Jagadeeswari, and Karri Srinivas. "Behaviour of M60 grade concrete by partial replacement of cement with fly ash, rice husk ash and silica fume." Materials Today: Proceedings 37 (2021): 2104-2108.
25. Srinivas, Karri, Sathi Kranthi Vijaya, and Kalla Jagadeeswari. "Concrete with ceramic and granite waste as coarse aggregate." Materials Today: Proceedings 37 (2021): 2089-2092.
26. Srinivas, K., L. Ponraj Sankar, and C. Kumara Swamy. "Experimental investigation on rapid strength gain by adding alccofine in high strength concrete." Materials Today: Proceedings 46 (2021): 925-929.
27. Mohiddin, Shaik Lal, Karri Srinivas, Sathi Kranthi Vijaya, and Kalla Jagadeeswari. "Seismic behaviour of RCC buildings with and without floating columns." Materials Today: Proceedings (2020).
28. Kalla, Jagadeeswari, Srinivas Karri, and Kranthi Vijaya Sathi. "Experimental analysis on modulus of elasticity of slag based concrete." Materials Today: Proceedings 37 (2021): 2114-2120.
29. Srinivas, Karri, Sathi Kranthi Vijaya, Kalla Jagadeeswari, and Shaik Lal Mohiddin. "Assessment of young's modulus of alkali activated ground granulated blast-furnace slag based geopolymer concrete with different mix proportions." (2021).