Enhancing the Durability of Concrete Structures with Recycled Aggregate

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***Abstract*— The building industry is heavily dependent on natural resources. Construction and demolition waste are the main problems. Reusing construction and demolition wastes helps the construction industry address economic and environmental issues. Discussing the possibilities of substituting recycled aggregate for natural aggregate in structural concrete, performance enhancement of recycled concrete aggregate from various sources is done in this article. with a focus on enhancing the performance of recycled concrete aggregate (RCA) from various sources. Factors such as the mechanical strength and durability of RCA are thoroughly investigated. The study also examines the effectiveness of incorporating additives like silica fume and basalt fiber to further improve the durability of recycled concrete. Highlighting the importance of using high-quality recycled aggregate and suitable modification treatments such as pozzolan slurries, fly ash, and nano-SiO2 solutions. By utilizing recycled aggregate, the construction industry can create stronger and more sustainable concrete structures.**

I. INTRODUCTION

Solid wastes, of which construction and demolition (c&d) wastes make up a significant percentage, are being produced at an accelerated rate in india. A result of the economy's and the construction industry's rapid expansion [1]. Generating enormous deposits of cdw and becoming an environmental issue. Other developing nations have put regulations into effect that limit cdw by restrictions or unique charges for establishing waste sites. Recycling leftover concrete from construction and demolition projects to create an alternative aggregate for structural is one approach to solving these issues. Recycled concrete aggregate (RCA) is often created by crushing and screening concrete debris to remove impurities such gypsum, paper, wood, and metal reinforcing. Recycled aggregate concrete, or RAC, is a type of concrete constructed utilising these recycled concrete aggregates[2] . Recently, resource preservationists and environmentalists have paid close attention to the efficient applications of recycled concrete aggregate (RCA) in the cement and concrete industries. Since aggregate normally makes up between 60 and 75 percent of concrete's volume, natural aggregate cannot be readily replicated. As a result, using leftover concrete as recycled aggregate not only addresses the issue of few resources, but also saves land that would have been needed for their disposal. However, due to the poor quality of RCA, its usage in the manufacturing of concrete may result in some mechanical issues and durability issues. Reported that using RCA to replace 50% or more of natural coarse and fine aggregate can drastically lower concrete's compressive strength [3].

Recycling aggregate as opposed to natural aggregate as a result, there is a large need for water, poor durability, and low strength and elastic modulus of concrete. Recycled aggregate, which is created by simply crushing and screening leftover concrete, has a rough surface, many sharp edges, and is mostly covered in old mortar when used directly as aggregate in concrete. Because of this, recycled aggregate needs to be adequately pre-treated before usage [4]. primary approaches for treating RCAs involve strengthening the adhered mortar and removing it. Strengthening methods aim to improve the properties of the old mortar in RCAs, often through techniques such as accelerated carbon dioxide curing, carbonation, adding nano and cementitious materials to the mixture. On the other hand, removing the adhered mortar involves techniques like ultrasonic cleaning or rubbing methods. Another common method is coating the surfaces of RCAs with pozzolanic materials, such as silica fume (SF) and fly ash (FA), to improve the quality of the adhered mortar. The slurry pozzolanic method helps fill the pores on the surface of RCAs and develop a stronger interfacial transition zone (ITZ) [5]. The growth of building debris wastes resulting from wars, earthquakes, natural disasters, and urban transformation projects has prompted countries to seek effective waste disposal solutions. One such solution is the utilization of construction and demolition waste (CDW) as recycled aggregates (RA) in concrete [2]. However, studies have pointed out that RA can negatively affect the physical, mechanical, and durability performance of concrete due to the presence of attached old mortar (AOM) content in the RA[3].Therefore, treatment methods for RCAs have been proposed, including AOM removal and AOM strengthening processes (such as polymer emulsion and pozzolan slurry [4]. Among these methods, environmentally friendly options like mechanical treatment, specifically abrasion treatment methods, have shown promising results[6] . Concrete durability is a critical factor for the longevity of concrete structures [1]. Permeability is a key parameter that affects concrete durability, and it is influenced by various components, ingredient proportions, and concrete mixing techniques [3].The use of RCAs in concrete tests to durability due to the permeability associated with the RCAs' essential characteristics and the presence of AOM. Durability concerns include water absorption, freeze-thaw resistance, water permeability, and chloride ion migration. to solve these problems and make recycled concrete stronger and more durable, one effective approach is to use denser materials that reduce the ability of water to pass through. Additionally, modifying the cement mixture with mineral additives can further improve its durability while reducing the need for natural resources and cement [2].

We present this thorough analysis of RA and RAC to fill in the gaps. the review approach is displayed. First, a summary of the history of RAC, the recycling, reuse, and manufacturing processes of RA, the mechanism, the mechanical, physical, and chemical qualities, as well as the ways for improving RAC's mechanical properties. Following that, models that are currently in use to predict RAC compressive strength, water absorption,water penetration response are provided. Thirdly, RAC's current practical applications in structural and non-structural fields are shown. Fourth, the difficulties of RAC application and the connection between CDW material and EU green policy are examined. Finally, the requirement for research on RAC is highlighted in the future.Major databases like Google Scholar, Scopus, and Web of Science were used to conduct a thorough review of RA and RAC. When conducting a search, keywords including recycled aggregate, recycled aggregate concrete, construction and demolition wastes, treatment of recycled aggregate, improvement methods for recycled aggregate concrete, fiber reinforced recycled aggregate concrete, and recycled aggregate concrete model were entered. The studies that were examined in this review were written between 2009 and 2023. Data filtering has been done to produce trustworthy results. Conference papers are not included in this study because they often offer less thorough information than journal publications.

II. MATERIAL

The strength and durability of recycled concrete is lower than those of Natural aggregate concrete (NAC) mainly because the surface of the Recycled aggregate (RA) adheres to mortar, which changes the surface properties of the RA.[12]investiget enhancement of durability in both recycled aggregate concrete (RAC) and treated recycled aggregate concrete (RAC) by utilizing an optimized Ball Mill Method (OBMM) with the combination of silica fume (SF) and basalt fiber (BF) The production involved utilizing CEM I Portland cement, and to enhance the concrete's performance, a polycarboxylate based superplasticizer admixture was used. [13] prepare recycled aggregate concrete (RAC) the collected recycled aggregates, specifically ORCAs with less than 5% impurities, from a local recycling plant. These aggregates were stored for over 1.5 years before use. In addition, river sand (<5 mm), ASTM Type I cement, and a superplasticizer (SP) were combined for the preparation of new concrete mixtures. [14] combine natural aggregates (limestone gravel and alluvial rolled sand) and recycled aggregates (RA) from five Portuguese CDW recycling plants (Valnor, Vimajas, Ambilei, Europontal, and Retria) were used in the concrete production. Cement CEM I 42.5 R and tap water were utilized. RA, except for those from Ambilei, had a higher shape index than the natural aggregates**.**Shaban et al., 2021) Utilized two types of coarse recycled concrete aggregates (RCA).untreated RCA and strengthened RCA. Strengthened RCA was prepared by modifying the surface.The concrete mixture included OPC grade 42.5 cement as the primary binding agent, along with pozzolanic materials for treating the RCA. [16]prepared recycled aggregates (RA) by crushing demolished concrete waste. The reinforced concrete (RC) was modified using a 10% salt solution composed of sodium sulfate, sodium chloride, and magnesium chloride. Fly ash and silica fume were added as admixtures, and the RA was treated with a 30% nano-SiO2 solution. Ordinary Portland cement (OPC) was used in the experimental process. [17] utilized Ordinary Portland Cement (OPC) that observed with the IS: 12269 standard, along with manufactured sand adhering to Zone II of IS: 383 (2016). Crushed stone aggregates (CSA) with a maximum size of 20 mm, conforming to IS: 383, were also used. Recycled concrete aggregate (RCA) was produced from concrete waste obtained from the demolition site of a water tank, with a measured water absorption of 6.4%. [18] The utilization of construction and demolition waste (CDW) for concrete production holds significant potential for recycling, leading to a reduction in economic and environmental costs associated with waste removal and a decreased demand for natural resources, particularly natural aggregates (NA), in construction projects.

III. MIX DESIGN

Recycled concrete aggregates (RCAs) have certain properties that can affect the durability of concrete. These include absorbing more water, having more tiny holes, being less dense, and having lower strength compared to natural aggregates (NAs). However, we can make the concrete more durable by using different mixing techniques. we can optimize the way we mix the ingredients and add special substances like silica fume and basalt fiber. These techniques help overcome the weaknesses of RCAs, making the concrete stronger and more resistant to damage, so it lasts longer and performs better. [19]Formulate with varying water-to-cement ratios (w/c) of 0.30, 0.35, and 0.40, using coarse natural aggregates. The cementitious materials content, consisting of 92% cement and 8% silica fume (SF) based on previous research, was set at 420 kg/m³. Two series of recycled aggregate concretes (RACs) were produced, and the recycled concrete aggregates (RCAs) underwent treatment using two methods: RACCM and RACCD. In the RACCM method, the RCAs were immersed in an SF slurry containing 1 liter of water and 250 grams of SF for every 8 kilograms of RCAs. On the other hand, in the RACCD method, the RCAs were placed in a desiccator for 2 hours, followed by an hour of being coated with SF slurry within the desiccator. Subsequently, the pretreated RCAs were transferred to a drying oven set at 45°C for a duration of 3 days.[20]include natural aggregate concrete (NAC), untreated recycled aggregate concrete (RAC) and treated recycled aggregate concrete (RAiC) were produced 84 concrete series .CEM I Portland cement was used. 84 concrete series included SF (5–10%), BF (0.25–0.50–1.0%) and combination of SF (5–10%) + BF (0.25– 0.50–1.0%) Polycarboxylate-based superplasticizer admixture was also use in mixes.[21] designed water/cement ratio of 0.55 and a cement content of 325 kg/m³, the concrete combined sand, 5-10 mm natural aggregates, and 10-20 mm natural aggregates. Replace the concrete with recycled concrete aggregates (RCAs) using the absolute volume method from 0% to 100%. A double mixing method was utilized, dividing the water into two parts and adding them in two stages during the mixing process.(Bravo et al., 2015) Prepare 33 concrete mixes. The mixes consisted of regular concrete (RC) and encompassed varying proportions of coarse natural aggregates (NA) replaced by crushed recycled aggregates (CRA) sourced from five different providers. Also, the mixes combined different replacement percentages (10%, 25%, 50%, and 100%) of the overall volume of fine NA, which were substituted with fine recycled aggregates (FRA) exclusively obtained from Vimajas, Europontal, and Ambilei. [22] prepared recycled aggregates, the concrete mixes were prepared with varying proportions (0%, 20%, 50%, and 100%) as replacements for natural aggregates. Additionally, fly ash was incorporated as cement replacements at 0%, 25%, and 35% by weight in Series I, while maintaining a constant water to binder ratio (W/B) of 0.55. In Series II,[23]desigend M30 concrete, a total of 36 mixes were carefully formulated. Covered varying levels of aggregate replacement, including 0%, 25%, 50%, and 100% by volume. Also, the water-cement ratio ranged between 0.4 and 0.5, while the cement content varied from 300 kg/m3 to 450 kg/m3.

IV. DURABILITY TEST ON CONCRETE

A. Compression test

The compression test for concrete with recycled coarse aggregate (RCA) helps us understand how strong and sturdy the concrete is when RCA is used instead of natural coarse aggregate.this test is important because it helps us determine if RCA can be effectively used in construction and if the concrete made with RCA is durable and of good quality. By using RCA, we can contribute to sustainable construction practices by recycling materials. [19]observed decrease in compressive strength as the water-to-cement (w/c) ratio increases for all mixes. This is due to increased porosity, permeable voids, and a weaker interfacial transition zone (ITZ). The incorporation of recycled concrete aggregates (RCAs) resulted in reductions of 23%, 21%, and 6% in compressive strength for w/c ratios of 0.30, 0.35, and 0.40, respectively. The presence of pore structures and weak layers in the RCAs is the primary reason for the reduced strength. [18]observed that for a 50% incorporation ratio, no loss in compressive strength was registered. While the incorporation of recycled aggregates (RA) generally leads to a decrease in compressive strength, the addition of superplasticizers can improve the compactness of the mix, effectively compensating for most of the strength loss. [23]Evaluate significant effect of the replacement ratio of aggregates on the strength properties of concrete. It was found that replacing natural aggregates with up to 25% recycled concrete aggregate (RCA) does not notably alter the strength properties of the concrete. However, beyond this replacement threshold, the compressive strength and modulus of elasticity of the RCA concrete are affected. [22]observed the same level of recycled aggregate replacement, but the use of fly ash as a partial replacement for cement generally causes a decrease in compressive strength. However, an exception was noted for the concrete mixture with 25% fly ash at 90 days, where no significant loss in strength was observed. On the other hand, when fly ash was added as an additional component to the cement, it resulted in an increase in compressive strength.

B. Rapid Chloride Penetration Test

Chloride penetration in concrete can cause corrosion of the reinforcement steel, leading to durability problems and expensive repairs. Even in concrete without cracks, chloride can enter through mechanisms like capillary absorption, fluid pressure, and diffusion. Diffusion occurs when the concentration of chloride on the surface of the concrete is higher than on the inside. To measure chloride penetration, tests were conducted using cylindrical self-compacting concrete samples, following the Rapid Chloride Penetration Test (RCPT) method specified in ASTM C1202, at different time intervals. [19]determined that Surface pretreatment methods enhance the resistance to chloride ion penetration, particularly as the w/c ratio increases. Combining pretreated recycled concrete aggregates (RCAs) in the mixes resulted in a decrease in TCP of 29.8% and 21.8% compared to series I mixes with w/c ratios of 0.35 and 0.40, respectively. Utilizing pretreated RCAs coated in a desiccator led to a reduction in TCP of 16.3% and 13.3% for mixes with w/c ratios of 0.35 and 0.40, respectively. [22]observed improved ability to resist chloride ion penetration was due to a few reasons. Firstly, using fly ash helped to make the pores in the concrete more evenly distributed in terms of size and shape. Secondly, as the fly ash reacted with water, it formed more C-S-H products that absorbed chloride ions and prevented their entry. Lastly, adding fly ash as a partial replacement for cement reduced the amount of water needed in the concrete.[18]indicated that the mixes combining recycled aggregate (RA) along with the use of superplasticizers demonstrated enhanced resistance to chloride penetration when compared to the mixes containing regular cement (RC) alone. observed that the addition of superplasticizers had a positive effect on the cement paste by helping to compact it, which effectively delayed the penetration of chloride ions. [14] Observed that the use of recycled aggregate (RA) in concrete tends to cause a slight increase in the chloride diffusion coefficient relative to regular cement (RC). Specifically, replacing fine aggregates with RA leads to higher diffusion coefficients. However, mixes incorporating both coarse and fine RA from Ambilei show no visible change in resistance to chloride ion penetration.

C. Water Absorption Test

The water absorption of recycled aggregate concrete (RAC) refers to its ability to absorb water. It is a measure of how much water the RAC can take in over time. This property is important as it can impact the durability and performance of the concrete. High water absorption can lead to increased porosity and vulnerability to moisture-related issues such as cracking, freeze-thaw damage, and degradation of the concrete. Therefore, controlling and minimizing water absorption is crucial in ensuring the long-term durability of RAC.[23]observed trend is that the durability of RCA concrete decreases with an increase in the percentage of RCA in the mix. This is primarily due to higher water absorption by RCA and the presence of porous mortar adhered to its surface, which can negatively affect the concrete's durability over time. [21] indicate its durability. Increasing non-carbonated recycled aggregates (NRCAs) leads to higher water absorption in RAC, while carbonated RCAs decrease water absorption. Natural aggregates (NAs) have lower water absorption than RCAs. Replacing NAs with RCAs increases water absorption in RAC, but carbonated RCAs reduce water absorption. [22]confirm that as the strength of recycled concrete decreases, its porosity increases, particularly in larger capillaries. The inclusion of fly ash as a partial cement replacement and additional cement significantly reduces water absorption in recycled aggregate concrete.

D. Water Penetration Test

A water penetration test is conducted to evaluate how effectively a material or structure can prevent the entry of water. By applying water to one side of the specimen and observing any visible signs of water penetration or leakage, this test assesses the specimen's water resistance and potential exposure to water-related damage. It helps in understanding if the material or structure can withstand exposure to water over time, ensuring the durability and integrity of buildings, bridges, and other constructions. The results of the test inform decisions on suitable construction methods, materials, and waterproofing techniques to mitigate potential water-related issues like leaks, mold, or deterioration. [24]Recycled aggregate concrete (RAC) allows water to pass through more easily than traditional concrete because the water moves faster through the recycled aggregate (RA) used in RAC compared to natural aggregate (NA). [25]Observed that using up to 25% fine recycled aggregate (RA) instead of fine natural aggregate in self-consolidating concrete (SCC) reduces water permeability. The positive effect on water permeability is credited to the mix design, which involves using more fine binders. [26]mentioned that adding fine ground bagasse ash (GBA) to recycled aggregate (RA) reduced the water permeability of the concrete. Similarly, using RA along with a large amount of ground granulated blast furnace slag (GGBFS) decreased the water absorption of recycled aggregate concrete (RAC). By adding 5% silica fume (SF) to recycled aggregate concrete (RAC), the water permeability decreased by 7.8%[27]. [28] Observed that use of fine aggregate (FA) in concrete helps improve the structure of the cement paste, making it more resistant to water penetration. This counteracts any potential increase in water permeability caused by recycled aggregate (RA) in the concrete.

V. CONCLUSION

1.The compressive strength of RAC is generally lower than NAC, with reductions ranging from 6% to 23% depending on the water-to-cement ratio and the percentage of recycled aggregates used. However, up to 25% replacement of natural aggregates with recycled aggregates not significantly affect the strength properties of the concrete

2.Pretreated recycled concrete aggregates (RCA) reduced total chloride penetration by approximately 21.8% to 29.8%. Additionally, the addition of fly ash as a partial replacement for cement decreased chloride ion penetration by approximately 16.3% to 13.3%. These measures significantly improve the resistance of concrete structures to chloride ion penetration, enhancing their durability.

3.Water penetration tests indicate that RAC tends to allow water to pass through more easily compared to NAC. The use of fine aggregate (FA) and certain additives like silica fume, ground granulated blast furnace slag (GGBFS), and bagasse ash can reduce water permeability and improve the resistance of RAC to water penetration.

4.Recycled aggregate (RA) in concrete can increase its permeability to water compared to traditional concrete. However, by adjusting the mix design and incorporating additives like bagasse ash, ground granulated blast furnace slag (GGBFS), or silica fume, the water permeability can be reduced by up to 25%.

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