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A Review of the Behavior of Structural Elements by using Recycled Coarse Aggregate Concrete.

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***Abstract*— This paper presents a comprehensive literature review on the use of recycled concrete aggregates (RCA) in construction, aiming to address the challenges of diminishing natural resources and increasing construction and demolition (C&D) waste. The review highlights the benefits and limitations of RCA and examines the impact of the RCA replacement ratio on the performance of concrete structures. The findings suggest that higher RCA content in concrete can lead to increased chloride ingress, steel corrosion, and cracking damage, which affect the long-term durability of concrete beams. The bond behavior between reinforced recycled aggregate concrete (RAC) and steel bars is influenced by the RCA replacement percentage and water-binder ratio, with higher RCA content and the presence of recycled fine aggregate (RFA) negatively affecting bond strength. Additionally, incorporating recycled asphalt pavement (RAP) and RCA in reinforced concrete beams can enhance shear capacity, but careful consideration of mix proportions is required. Optimal proportioning of recycled coarse aggregate, preprocessing of RCA, and reevaluation of design provisions are crucial for the successful utilization of RCA in construction. Further research is recommended to explore the behavior of structures using RAP and RAP-RCA in different structural members. By embracing RCA, the construction industry can contribute to a more sustainable future by conserving natural resources and diverting C&D waste from landfills.**

Keywords:- Recycled Concrete Aggregates (RCA), Construction And Demolition (C&D) Waste, Natural Resources, Durability, Chloride Ingress, Steel Corrosion, Cracking Damage, Bond Behavior, Recycled Fine Aggregate (RFA), Recycled Asphalt Pavement (RAP), Shear Capacity.

I. INTRODUCTION

The rapid population and economic growth worldwide, including both developed and developing countries, have led to significant demand for infrastructure development. However, this increased construction activity has resulted in the depletion of natural resources. Additionally, industrialization and urbanization have further contributed to the generation of large amounts of construction and demolition (C&D) waste. Safe disposal of this waste has become a pressing issue for the construction industry. To address the dual challenge of diminishing natural resources and growing C&D waste, recycling C&D waste for use in new construction has emerged as a viable solution. One attractive option is the reuse of old concrete as a source of aggregate in new concrete, particularly in cases where the waste concrete percentage is high. Demolished buildings, concrete road bases, rejected precast concrete members, unused concrete from mixing plants, and tested specimens from laboratories are all potential sources of waste concrete that can be recycled and incorporated into new construction projects. [1]

One promising approach is recycling demolished concrete as recycled concrete aggregates (RCA). This practice reduces the demand for new aggregates and helps divert construction waste from landfills, conserving natural resources, reducing energy consumption, and promoting a circular economy. By embracing the use of RCA, the construction industry can address these challenges while moving towards a more environmentally friendly and resource-efficient future. [2]

II. RECYCLE COARSE AGGREGATE

Recycled concrete aggregates (RCA) are obtained from the demolition of concrete structures in civil construction activities. RCA consists of concrete particles with varying amounts of natural aggregates (NA) and cement. However, RCA has certain weaknesses compared to natural aggregate (NA) due to the presence of attached mortar on its surface. This mortar leads to increased porosity in RCA, characterized by a higher percentage of capillary pores and microcracks, sometimes even in the interfacial transition zone (ITZ) between the aggregate and cement paste. The porosity of RCA is influenced by the original composition of the concrete mixture and the process of producing the recycled aggregate. Numerous studies have demonstrated that RA exhibits inferior physical and mechanical properties compared to NA. When used in concrete, RA has been found to reduce workability, compressive strength, split tensile strength, flexural strength, and other engineering properties in comparison to NA. Consequently, preprocessing of RA is necessary before incorporating it into concrete to overcome these limitations and enhance its performance. [1]

Fig. 1 Natural coarse aggregate

Fig. 2 Recycle coarse aggregate

III. LITERATURE REVIEW

The research works published by several researchers in various journals have been reviewed and are presented in the following section:

(Peng et al., 2021)

This study examined the effects of recycled coarse aggregate (RCA) replacement ratio on the long-term behavior of concrete beams subjected to loading and chloride attacks. Higher RCA replacement ratios resulted in increased chloride ingress, severe steel corrosion, and cracking damage, leading to decreased flexural capacity. Transverse and longitudinal cracks were more prominent on the concrete surface with higher RCA content. The chloride content and steel corrosion were highest near the loading points. The RCA replacement ratio did not affect the failure modes but influenced concrete strain, deflection, and flexural capacity. Overall, the study concluded that the RCA replacement ratio significantly impacts the long-term performance and durability of concrete beams.

(Dong et al., 2019)

This research examined the bond behavior between reinforced recycled aggregate concrete (RAC) and steel bars under flexural conditions. The study conducted tests on fifteen beam specimens with varying parameters. The results showed that the bond strength between RAC and steel bars decreased with increasing recycled coarse aggregate (RCA) replacement percentage, but the rate of decrease was lower for specimens with lower water-binder ratios. The addition of recycled fine aggregate (RFA) negatively affected the bond behavior. Deformed reinforcements exhibited stronger bond strength compared to plain reinforcements. The reinforcement surface shape and anchorage length also influenced the bond behavior. The study concluded that a proposed constitutive model accurately described the bond-slip relationship in reinforced RAC.

(Arabiyat et al., 2021)

This study investigated the shear behavior of thirteen reinforced concrete beams made with Recycled Asphalt Pavement (RAP) and Recycled Coarse Aggregate (RCA). The beams were tested and compared with theoretical results from international codes and fracture mechanics approaches. The experimental shear capacity was found to increase as the RAP and RCA replacement levels decreased for certain groups of beams. The theoretical shear strength capacities were generally more conservative but still applicable. Overall, using RAP and RCA in RC beams was considered an effective approach. The study concluded with recommendations for optimal recycled mix proportions based on the experimental shear capacity.

(Shatarat et al., 2019)

This study investigated the axial compressive behavior of fifteen reinforced concrete columns constructed using different types of aggregates: Natural Aggregate (NA), Recycled Asphalt Pavement (RAP), Recycled Coarse Aggregate (RCA), and a combination of RAP and RCA (RAP-RCA). The columns were tested and compared with theoretical values from ACI and Japanese codes. The experimental results showed that the axial capacity of the columns decreased as the RAP, RCA, and RAP-RCA contents increased. However, the theoretical values were more conservative but still applicable. The study concluded that using RAP, RCA, and RAP-RCA in concrete columns is a safe and promising approach. The maximum recommended replacement levels were determined for each type of aggregate. Further research is recommended to explore the durability, flexural, and shear behavior of structures using RAP and RAP-RCA in other structural members.

(Al Mahmoud et al., 2020)

This study investigated the effects of replacing natural aggregates with recycled coarse and fine aggregates on the shear behavior of reinforced concrete beams. The results showed a decrease in shear strength when recycled aggregates were used, especially with higher replacement ratios. However, the shear behaviors of the recycled concrete beams were comparable to those of beams with natural aggregates in terms of load-deflection response. Significant cracking was observed in the recycled concrete beams, and all specimens failed in a classical shear failure mode. The study also found that existing standards tended to be conservative when predicting the shear capacity of recycled aggregate concrete beams.

(Zheng et al., 2021)

This study focuses on investigating the shear behavior of reinforced recycled aggregate concrete (RRAC) beams under elevated temperatures. RRAC beams were tested at different levels of recycled coarse aggregate (RCA) replacement and elevated temperatures. The results showed that increasing temperatures caused changes in concrete color and reduced the shear performance of RRAC beams. The shear damage and mechanisms were similar to those of reinforced natural aggregate concrete (RNAC) beams at the same temperatures. Finite element simulations were conducted, and six design provisions were evaluated to assess the residual shear capacity of RRAC beams. It was found that existing provisions derived from RNAC underestimated the residual shear capacity of RRAC beams at temperatures up to 500°C. The study also highlighted the influence of RCA replacement percentage, temperature, transverse reinforcement spacing, and shear span-to-depth ratio on the shear behavior of RRAC beams.

(Liu et al., 2021)

This study aimed to investigate the flexural rigidity healing of microbial self-healing concrete using recycled coarse aggregates (RCA) as a bacterial carrier. Through theoretical analysis and experimental observations, it was found that after 28 days of healing, the flexural rigidity healing ratio of the specimens using RCA as the bacterial carrier reached 12.25%. This ratio increased to 53.02% after 56 days of healing. The presence of microbial-induced calcium carbonate ($CaCO_3$) precipitates in the cracks contributed to the healing process, with the healed crack width reaching up to 0.25 mm. The study demonstrated the effectiveness of the microbial self-healing approach, highlighting the potential of using RCA in concrete for sustainable crack repair and improved structural performance.

(Kim & Yun, 2013)

This study conducted 144 tests to investigate the bond behavior of deformed bars in recycled aggregate concrete (RAC). The variables considered were aggregate size, RCA replacement ratios, bar directions, bar locations, and concrete aging. The results showed that RAC-I specimens with a 20mm maximum RCA size had greater bond strength than RAC-II specimens with a 25mm maximum RCA size. The bond strength of RCA was influenced by aggregate size due to the spherical shape of RAC. Increasing RCA replacement ratios led to a proportional decrease in compressive strength. Aging had little effect on bond strength but affected compressive strength.

IV. CONCLUSION

In summary, the reviewed literature suggests the following key points:

1. The replacement ratio of recycled coarse aggregate (RCA) significantly affects the long-term performance and durability of concrete structures, with higher RCA content leading to increased chloride ingress, steel corrosion, and cracking damage.
2. The bond behavior between reinforced recycled aggregate concrete (RAC) and steel bars is influenced by the RCA replacement percentage and water-binder ratio, with higher RCA content and the presence of recycled fine aggregate (RFA) negatively impacting bond strength.
3. Using recycled asphalt pavement (RAP) and recycled coarse aggregate (RCA) in reinforced concrete beams can increase shear capacity, but proper mix proportions should be considered, and theoretical calculations may be more conservative than experimental results.
4. The shear behavior and axial compressive behavior of concrete structures using RCA can be affected, with higher RCA content leading to a decrease in shear and axial capacities. However, theoretical values derived from codes are generally applicable, although conservative.

Overall, optimizing the proportion of recycled coarse aggregate in concrete mix designs, considering bond behavior, and reevaluating existing design provisions are crucial for successfully incorporating RCA in construction practices.

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