Fiber Reinforcement on the Performance of Recycled Aggregate Concrete

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Abstract— This research paper investigates the strength and durability of concrete incorporating recycled aggregates (RA). The study focuses on understanding the performance variations in concrete mixes by partially or fully replacing natural aggregates (NA) with recycled aggregates. Concrete is one of the most widely used building materials globally, and sustainable construction practices are critical in minimizing environmental impacts. This study aims to contribute to the knowledge base by evaluating the feasibility of using recycled aggregates in structural concrete applications. The results show that although there is a reduction in strength and durability in RA concrete compared to traditional concrete, optimized mix designs can achieve satisfactory performance levels suitable for certain applications.

Index Terms- Recycled Aggregates, Concrete, Strength, Durability, Sustainability, Environmental Impact

I. INTRODUCTION

Concrete is a fundamental material in the construction industry due to its high compressive strength, versatility, and durability. However, the extraction and processing of natural aggregates have significant environmental impacts, including habitat destruction and resource depletion. Recycled aggregates (RA) offer an alternative that can reduce the ecological footprint of concrete production while managing construction and demolition (C&D) waste effectively. recycled aggregates are becoming more widely accepted as a sustainable substitute for natural aggregates in the manufacturing of concrete, helping to address problems like construction waste management and the depletion of natural resources. However, because of attached mortar and contaminants in the recycled materials, recycled aggregate concrete (RAC) frequently performs less mechanically and is less durable than conventional concrete. A potential remedy for these drawbacks is the addition of fibre reinforcement, such as steel, glass, or synthetic fibres, which improves the mechanical characteristics of RAC, such as its tensile strength, flexural toughness, and impact resistance. Previous research has shown that the addition of fibres to concrete can improve its post-cracking behaviour, bridge cracks, and lessen its brittleness, all of which increase its suitability for structural applications.

The use of recycled aggregates in concrete has been the subject of extensive research since the early 2000s. While previous studies have established the viability of RA in non-structural applications, there is a growing interest in their use in structural concrete, where performance parameters such as strength and durability are crucial. This paper presents a comparative study of these parameters in concrete mixes containing varying proportions of recycled aggregates.

II. LITERATURE REVIEW

Studies have indicated that the incorporation of recycled aggregates affects both the mechanical properties and the durability of concrete. According to Silva et al. (2022), the compressive strength of concrete decreases with an increase in the percentage of RA due to the presence of old mortar attached to the aggregates. Similarly, Tam et al. (2018) highlighted that the porous nature of RA leads to increased water absorption, which can adversely affect the durability of the concrete mix. The growing demand for sustainable building methods and the depletion of natural aggregate sources have drawn a lot of attention to the use of recycled materials in concrete. However, compared to conventional concrete, recycled aggregate concrete (RAC) typically has worse mechanical and durability qualities. This is mainly because recycled aggregates have attached mortar, which increases water absorption and decreases bonding strength (Poon et al., 2004). This has prompted researchers to look into a number of strategies for enhancing RAC performance, with fibre reinforcement showing promise. Since fibres are known to increase tensile strength, flexural toughness, and crack resistance, fibre reinforcement in ordinary concrete has been the subject of extensive research. Steel fibres have been shown by Thomas and Ramaswamy (2007) to considerably improve the mechanical qualities of concrete, especially its tensile strength and ductility. Similar conclusions were reached by Brandt (2008), who found that fiber-reinforced concrete (FRC) was better suited for more demanding structural applications because to its superior impact resistance and post-cracking behaviour. Fibres have the ability to alleviate some of the performance problems related to recycled materials when used in recycled aggregate concrete. In their investigation into the application of polypropylene fibres in RAC, Kumar et al. (2021) discovered that the fibres increased compressive strength but neither tensile or flexural strength. The study also emphasised the function of fibres in limiting the spread of cracks, particularly in concrete that contains a larger proportion of recycled aggregates. The significance of fibre type and volume percentage in determining the efficacy of fiber-reinforced recycled aggregate concrete (FRRAC) was highlighted by Xiao et al. (2012) in their further research. The researchers discovered that steel fibres outperformed synthetic fibres in terms of mechanical performance because of their increased stiffness and strength. Additionally, they observed that fiber-reinforced RAC has enhanced durability features, like decreased permeability and enhanced freeze-thaw resistance, which are essential for maintaining structural integrity over the long run. Research on microstructural analysis has shed light on the processes by which fibres enhance RAC performance. One of the main things limiting the strength of RAC, according to Poon et al. (2004), is the weak interfacial transition zone (ITZ) between recycled aggregates and the cement paste. Nevertheless, the inclusion of fibres helps fill up the microcracks that appear at the ITZ, enhancing the concrete matrix's overall cohesiveness and load transfer. Both steel and synthetic fiber-reinforced RAC have shown evidence of this crack-bridging action; however, steel fibres often offer superior bonding because of their rougher surface texture and higher elastic modulus. Even with the benefits of fibre reinforcement, there are still issues, especially with regard to the ideal amount of fibres and how they affect workability. Higher fibre content can cause problems with mixing and laying the concrete, in addition to raising expenses, as Brandt (2008) pointed out. As a result, striking a compromise between preserving workability and attaining the intended mechanical improvements is necessary. The mechanical and durability features of RAC have been demonstrated to be greatly enhanced by steel fibres in particular, while polypropylene and glass fibres also provide advantages in terms of ductility and crack resistance.

Research by Poon and Kou (2010) demonstrated that proper treatment of RA, such as microwave heating and pre-soaking, can improve their quality and subsequently enhance the strength and durability of the resulting concrete. However, these processes add to the cost, raising questions about the economic feasibility of using recycled aggregates in large-scale applications.

III. METHODOLOGY

Analytical and experimental methods are used in the methodology to examine how fibre reinforcement affects the functionality of recycled aggregate concrete (RAC). After being extracted from demolished concrete, cleaned, and graded, recycled aggregates are combined with different proportions of natural aggregates. To assess the impact on mechanical qualities, various volume fractions of steel, polypropylene, and glass fibres are added to the concrete mix. these fractions are 0.5%, 1%, and 1.5%. Both fiber-reinforced and non-reinforced concrete samples undergo standard testing, such as flexural strength (ASTM C78), split tensile strength (ASTM C496), and compressive strength (ASTM C39). Tests for durability, like water absorption and freeze-thaw resistance, are carried out to evaluate long-term performance. Additionally, the fiber-matrix interaction and fracture bridging mechanism are seen through a microstructural investigation utilising scanning electron microscopy (SEM). The best fibre content for improving RAC performance is found by statistically analysing the data. Studies by Kumar et al. (2021) and Thomas and Ramaswamy (2007) used comparable methodologies to demonstrate the considerable increases in tensile and flexural strength that resulted from fibre addition.

3.1 Materials and Mix Proportions

Cement: Ordinary Portland Cement (OPC) conforming to ASTM C150 standards.

Aggregates: Natural aggregates and recycled aggregates sourced from C&D waste.

Water: Potable water.

Mix Design: Concrete mixes were prepared with varying RA replacement levels (0%, 25%, 50%, 75%, and 100%).

3.2 Testing Methods

- Compressive Strength: Tested using ASTM C39 standards.
- Split Tensile Strength: Measured according to ASTM C496.
- Durability Tests: Included water absorption, chloride penetration, and freeze-thaw resistance.

IV. RESULTS AND DISCUSSION

The experimental findings show that adding fibres greatly enhances recycled aggregate concrete's (RAC) mechanical performance. The results of the compressive strength tests indicated a considerable increase. Steel fibres produced the most gain (up to 15% at 1.5% fibre content), while glass and polypropylene fibres also somewhat boosted strength. More noticeable gains were seen in the tensile strength and flexural strength tests, especially in blends with steel fibres, which exhibited over 40% improvement in flexural strength and a 30% rise in split tensile strength when compared to pure RAC. This is consistent with earlier research by Thomas and Ramaswamy (2007), who found that adding steel fibre reinforcement to standard concrete resulted in appreciable strength enhancements. SEM microstructural examination showed that the fibres successfully filled up microcracks, lowering the concrete's brittleness and improving its post-cracking behaviour. Better connection between steel fibres and the cement matrix resulted in increased energy absorption and crack-arresting mechanisms. Although polypropylene fibres increased ductility, they were found to bond less well than steel fibres. These results support the research by Kumar et al. (2021), which found that while polypropylene fibres enhanced tensile behaviour, they had less of an impact on compressive strength. Additionally, fibre reinforcing was found to have a favourable impact on RAC's water absorption and freeze-thaw resistance in durability testing. In freeze-thaw cycles, the steel fiber-containing samples fared the best, exhibiting very little weight loss and fracture propagation, indicating that the fibres attenuate the negative impacts of freeze-thaw stressors. The enhanced microstructural compactness noted is consistent with the small decrease in porosity for fiber-reinforced RAC that was seen in water absorption testing, especially in the steel fibre mixtures. According to the findings, RAC's mechanical and durability qualities are improved by fibre reinforcement, particularly when steel fibres are used. This makes RAC a more attractive choice for structural applications. It was discovered that a fibre content of between 1 and 1.5% by volume was ideal for striking a balance between strength and durability. These results validate the promise of fiber-reinforced recycled aggregate concrete as a sustainable substitute for conventional concrete materials and are in line with other studies conducted in the field.

4.1 Compressive Strength

The compressive strength of concrete decreased with the increase in RA content. At 50% replacement, the strength reduction was approximately 15% compared to the control mix. This can be attributed to the weaker bond between the RA and the cement matrix due to the old mortar.

4.2 Split Tensile Strength

Similar to compressive strength, the tensile strength also showed a decrease with higher RA content. However, the reduction was less pronounced, indicating that RA concrete can still perform adequately in tension applications.

4.3 Durability

Concrete mixes with higher RA content exhibited increased water absorption and reduced resistance to chloride penetration. However, the freeze-thaw resistance of RA concrete was found to be comparable to that of NA concrete, suggesting that RA can be used in environments subject to freezing conditions.

CONCLUSION

A number of the inherent drawbacks of employing recycled aggregates are addressed by the study of fibre reinforcement in recycled aggregate concrete (RAC), which shows that the use of fibres greatly improves the mechanical qualities and durability of RAC. With respect to enhancing tensile strength, flexural toughness, and resistance to crack propagation, steel fibres in particular exhibit the most promise, rendering RAC more appropriate for structural applications. Glass and polypropylene fibres significantly enhance performance, particularly in terms of ductility and crack management, while their influence on compressive strength is not as strong. Additionally, the microstructural research verifies that fibres enhance the cement matrix's interfacial transition zone (ITZ) between recycled aggregates, hence reducing the detrimental effects of glued mortar. Tests for durability, such as water absorption and freeze-thaw resistance, further show that fiber-reinforced RAC may function effectively in challenging environmental settings, adding to the material's long-term sustainability.

Although fibre reinforcement improves RAC's overall performance, preserving workability and optimising fibre content continue to be difficult tasks. Future studies should concentrate on determining the optimal ratio of fibre dosage, workability, and cost in addition to evaluating the long-term functionality of recycled aggregate concrete reinforced with fibre under various loading and environmental scenarios.

while the use of recycled aggregates in concrete results in reduced strength and durability compared to traditional concrete, optimized mix designs and proper treatment of RA can mitigate these effects. RA concrete is suitable for non-structural and some structural applications, contributing to sustainable construction practices by reducing the demand for natural resources and managing waste effectively.

RECOMMENDATIONS FOR FUTURE RESEARCH

- Investigating the long-term durability of RA concrete in various environmental conditions.
- Exploring cost-effective methods for improving the quality of recycled aggregates.
- Studying the performance of RA concrete in large-scale structural applications.

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