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PRELIMINARY STUDY ON RECYCLED BRICK AGGREGATE CONCRETE MIXED WITH RIVER SAND AND SEA SAND

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ABSTRACT

This study examines the feasibility of making concrete by using sea sand and recycled brick aggregate as substitute materials for river sand and natural coarse aggregate, respectively. A total of six cases were investigated; each case contained nine cylindrical concrete specimens (100 mm by 200 mm) prepared with 100% recycled brick aggregates, cement content of 340 kg/m^3, water-to-binder ratio (W/B) of 0.45, and sand-to-aggregate volume ratio (s/a) of 0.44. Additionally, 30% and 70% of the amount of CEM Type I was substituted by volume with ground granulated blast furnace slag (GGBFS) as cementitious material. Concrete specimen made with river sand and freshwater was used as control case. Slump tests were used to assess the fresh characteristics; the results ranged from 83 mm to 113 mm. Hardened properties, including compressive strength and ultrasonic pulse velocity (UPV), were assessed at 7 and 28 days, with split tensile strength measured at 28 days. Results for compressive strength indicate that at 28 days, concrete with sea sand, freshwater, and 30% slag had a 10.35% strength improvement over the control mix. UPV measurements confirmed satisfactory internal concrete quality across all mixes. 28-day split tensile strengths ranged from 3 MPa to 7 MPa. The constant demand of natural resources for concrete production, such as river sand, is leading to disruption of the local ecosystems. To mitigate this issue, the utilization of sea sand and recycled brick aggregates could be a viable option. This study demonstrates the potential of alternative materials for producing structurally sustainable concrete, supporting environmentally resilient construction practices.

Keywords: *Compressive strength; recycled brick aggregate; river sand; sea sand; split tensile strength.*

INTRODUCTION

Concrete is one of the most widely used material for construction purpose with an annual consumption estimation of approximately three tonnes (Miller et al., 2016). A huge raw materials and resources get consumed every day due to the production. As construction activities continue to grow, this demand is expected to rise further, resulting in depletion of natural resources over the years. Rapid urbanization has resulted in uncontrolled sand mining. Again, the coastal areas usually face a restriction on availability of natural aggregates (Zhang et al., 2024). Additionally, due to rapid construction and demolition, huge amounts of concrete residue get wasted due to a lack of proper recycling. This causes a great loss of resources and pollution.

There has been a significant shift towards the development of sustainable, "green" concrete through the incorporation of alternative materials in response to these growing environmental challenges. Among these, sea sand, recycled coarse aggregate (RCA), and slag have gained considerable attention as suitable substitutes for traditional mixing components (Alnahhal & Aljidda, 2018; Rahal, 2007; Tam et al., 2018). Sea-sand can be used as a smooth aggregate substitute due to its smooth and rounded texture which is great for concrete constituent materials (Sanjaya et al., 2021). The mechanical properties of such combined specimens show promising results in some aspects (Saxena & Baghban, 2023). Sea-sand and normal water combination can promote the highest final-day compressive strength, promoting the feasibility of using it as replacement for conventional resources (Ganesan et al., 2022; Jose et al., 2019). Utilizing RCA not only offers an effective method for reducing construction and demolition waste but also provides an alternative aggregate source that reduces pressure on natural reserves. Use of 30% recycled aggregate had the lowest chloride penetration after two weeks of saturation and performed better than a concrete mix with 100% natural aggregate (Ben & Alhumoud, 2019).

Cement types can also influence the chloride diffusion phenomena (Mohammed et al., 2003). Studies show that concrete composed of slag cement causes lower chloride ingression than ordinary portland cement (OPC). With the increase of Ground granulated blast-furnace slag (GGBFS) content, the chloride/iodide concentration gradually decreases (Jin et al., 2024). Hence, mineral admixture dosage can be used based on the requirement to enhance the strength and durability of concrete while offering reductions in waste (Srinath et al., 2021).

Nevertheless, incorporating these unconventional materials into concrete mixes introduces several challenges. A key issue is the heightened risk of reinforcement corrosion caused by chloride ions present in sea sand, which restricts the use of sea-sand concrete in reinforced structural applications. However, the inclusion of supplementary cementitious materials (SCMs) such as ground granulated blast-furnace slag (GGBFS) has been shown to improve the durability of concrete by binding free chlorides and enhancing the corrosion resistance of embedded steel (Li et al., 2017).

With the increasing availability of waste brick materials and declining availability natural sand, combining sea sand with recycled brick aggregates offers an environmentally sustainable solution for construction. This approach helps minimize environmental impact while ensuring structural performance, especially in coastal and marine engineering. The objectives of this study is to explore the mechanical performance of concrete incorporating sea sand and recycled brick coarse aggregate and to contribute theoretical insights for the practical use of these sustainable materials in coastal and marine infrastructure.

METHODOLOGY

2.1 MATERIALS AND MIX PROPORTIONS

CEM TYPE I cement was used as binder material in this study with cement content of 340 kg/m^3. Ground granulated blast-furnace slag (GGBFS) was used as alternative cementitious material that replaced CEM TYPE I by 30% and 70%, respectively. 100% recycled brick aggregates were used as coarse aggregates. River sand and sea sand were used as fine aggregates. The nominal size of the coarse aggregate was 20 mm. The gradation was controlled according to ASTM C33 (ASTM, 2023a). Specific gravity of cement, slag, river sand, sea sand, and recycled brick aggregates were 3.10, 2.90, 2.54, 2.28, and 2.10, respectively. Normal potable freshwater was used for concrete casting.

1.2 Test Specimens

A total of six cases were investigated, presented in **Table 1**. In each case, nine cylindrical concrete specimens (100 mm by 200 mm) were prepared with 100% recycled brick aggregate, 100% freshwater, binder content of 340 kg/m^3, water-to-binder ratio (W/B) of 0.45, and sand-to-aggregate volume ratio (s/a) of 0.44. Among the six mixes, cases one to three contained 100% river sand and case four to six contained 100% sea sand. Concrete specimens made with freshwater with 100% CEM TYPE I was used as control case (Mix 1: R-340-0).

Tabel 1: Mix Designs

Sl.	**Mix**	**CEM TYPE I**	**Slag**	**Fine Aggregate**	**Coarse Aggregate**	**Water**
		(kg/m^3)	**(kg/m^3) (%)**	**(kg/m^3)**	**(kg/m^3)**	**(kg/m^3)**
1	R-340-0	340	0 (0)	802	844	153
2	R-340-30	238	95 (30)			
3	R-340-70	102	223 (70)			
4	S-340-0	340	0 (0)	720	844	
5	S-340-30	238	95 (30)			
6	S-340-70	102	223 (70)			

Note: R = River sand, S = Sea sand, 340 = Binder Content in kg/m^3, 0, 30 and 70 are the volume replacement percentage of CEM TYPE I with slag powder.

1.3 Methods of Evaluation

1.3.1 Workability Test

The slump test, which measures the flow of fresh concrete, was carried out in accordance with ASTM C143 (ASTM, 2003). The procedure is pouring concrete into a slump cone, removing the cone, and measuring the slump—that is, the height difference between the top of the cone and the highest point of the concrete. More workability is indicated by a higher slump, whilst less workability is suggested by a lower slump.

1.3.2 Ultrasonic Pulse Velocity

Ultrasonic pulse velocity (UPV) is a non-destructive test used to assess concrete’s homogeneity, quality, and internal defects, following ASTM C597 (ASTM, 2023b). In this test, a pair of transducers (one emitting and one receiving the ultrasonic pulse) are placed on opposite surfaces of the concrete specimen. The time taken for the pulse to travel through the concrete is measured, and from this, the pulse velocity is calculated. Concrete quality is categorized based on UPV values as shown in Table 2.

Table 2. Concrete quality with respect to pulse velocity (BIS 13311-92-Part-I)

UPV	Concrete Quality
>4500 m/s	Excellent
3500-4500 m/s	Good
3000-3500 m/s	Fair
<3000 m/s	Poor

1.3.3 Compressive Strength

By following the procedures outlined in ASTM C39 (ASTM, 2017), the compressive strength of concrete was evaluated at different curing intervals specifically at 7 and 28 days. Three concrete specimens were examined each day.

1.3.4 Split Tensile Strength

The split tensile strength test measures the tensile strength of concrete under a direct tension load according to ASTM C496 (ASTM, 2011). Three concrete specimens were tested after 28 days of curing. This test helps to determine the ability of concrete to withstand tensile stresses, which is vital for assessing concrete's cracking resistance and durability in structures subjected to tensile forces.

3. RESULTS AND DISCUSSIONS

3.1 Workability Test

Figure 1 shows the slump values of fresh concrete. There is no significant variation of slump values containing river sand and sea sand with 0% and 30% slag replacement. Due to its finer particles and the presence of chloride ions, sea sand accelerates the initial hydration of cement. This rapid reaction causes the cement paste to stiffen and set more quickly, resulting in a faster and more pronounced loss of workability, similar to that observed in river-sand mixes (Wang et al., 2023). Additionally, slump value increases with the increase of slag percentage in the concrete mix; higher slag content increases slump by improving flowability and reducing water demand (Younis & Ebead, 2020). As a result, sea sand combinations with 70% slag content shows the highest slump value of 112.5 mm.

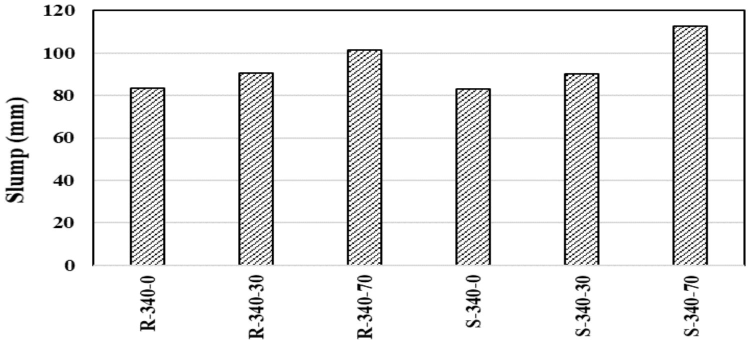


Figure 1. Slump values

3.2 Ultrasonic Pulse Velocity

Figure 2 illustrates the ultrasonic pulse velocity values of hardened concrete. Concrete made with recycled coarse aggregates (RCA) typically shows reduced ultrasonic pulse velocity (UPV) compared to mixes containing natural aggregates. This is primarily due to the inherent characteristics of RCA, such as higher porosity, the presence of pores and cracks, and weaker interfacial zones between the RCA and the cement paste (Ben & Alhumoud, 2019). Void percentage can be reduced by adding slag in the mix, that results in denser concrete matrix (Sanjaya et al., 2021). According to **Table 2**, UPV values are typically categorized as excellent (above 4.5 km/s), good (3.5-4.5 km/s), fair (3.0-3.5 km/s), and poor (below 3.0 km/s). According to concrete quality limits based on pulse velocity, maximum specimens ranged within medium to good quality on 28 curing days. UPV testing demonstrated that every mix achieved a satisfactory level of internal concrete integrity.

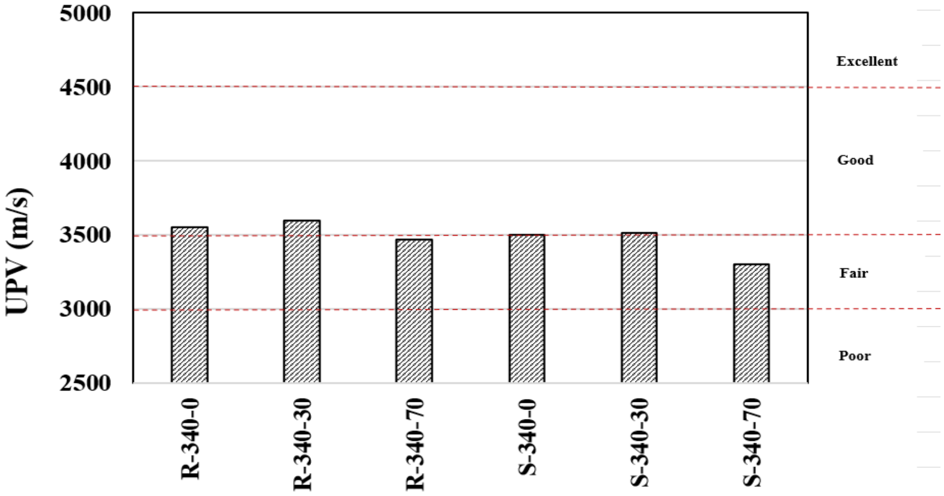
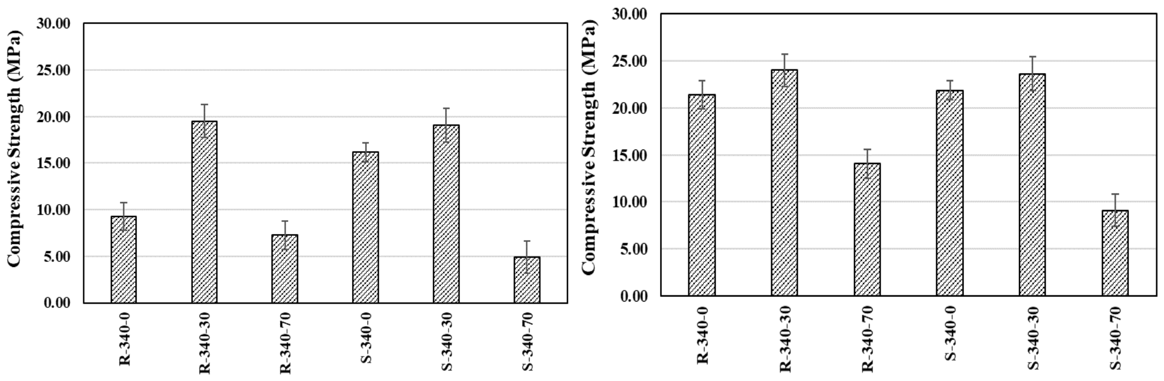


Figure 2. UPV values

3.3 Compressive Strength Test

Figure 3 shows the compressive strength of mixes at 7 days (a) and 28 days (b), respectively. After 7 days, the compressive strengths of river sand and freshwater combinations with 0%, 30%, and 70% slag replacement are 9.26 MPa, 19.52 MPa, and 7.25 MPa, respectively. The compressive strengths of sea sand combinations with 0%, 30%, and 70% slag replacement are 16.15 MPa, 19.07 MPa, and 4.90 MPa, respectively. For 28 days, the compressive strengths of river sand and freshwater combinations with 0%, 30%, and 70% slag replacement are 21.41 MPa, 24.01 MPa, and 14.05 MPa, respectively. Compressive strength of sea sand and freshwater combinations for 0%, 30%, and 70% slag replacement are 21.88 MPa, 23.63 MPa, and 9.10 MPa, respectively. Both combinations show maximum strength for 30% slag replacement and minimum strength for 70% slag replacement. As slag percentage increases, compressive strength also increases to an extent due to additional formation of CSH gel and void reduction, leading to a denser and more compact concrete matrix (Jose et al., 2019). But at high percentage, such as at 70% replacement, cement content is significantly reduced which leads to less calcium hydroxide and slower hydration. As a result, compressive strength of later ages gets compromised



(a)

(b)

Figure 3. Compressive Strength (a) 7 days, (b) 28 days

Figure 4 shows 7 days and 28 days compressive strength comparison with the control case where no slag replacement and no sea sand were used. After 7 days, compressive strength of mix 2 increased by 110.69% due to additional formation of CSH gel and void reduction at 30% slag (Mohammed et al., 2003). Compressive strength of mix 5 increased by 105.83% due to the accelerating effect of chlorides, present in sea sand, on early hydration (Pan et al, 2021). After 28-days of curing, compressive strength of mix 2 and mix 5 raised by 12.14% and 10.35% for 30% slag replacement. So, it can be summarized that whether using river sand or sea sand, along with 100% recycled brick aggregates, the optimum value of slag replacement is 30%. Furthermore, using sea sand in combination with recycled brick aggregates appears to be a viable option, as it produces compressive strength levels comparable to those of mixes made with river sand.

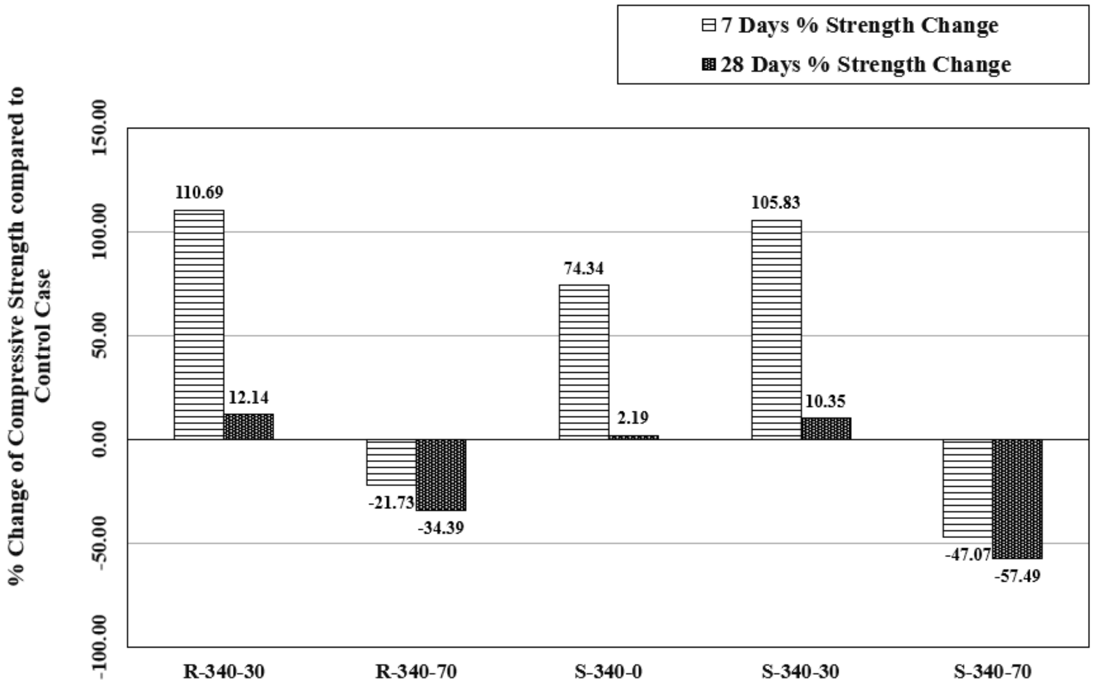


Figure 4. % Change of 7 days and 28 days compressive strength with respect to control case

3.4 Split Tensile Strength

Figure 5 depicts the split tensile strength of concrete at 28 days. Concrete with sea sand exhibits lower tensile strength than river sand concrete for 30% and 70% slag replacement levels; the strength is highest, approximately 6.90 MPa, at 0% slag replacement in sea sand concrete. This strength reduction may have occured due to the presence of impurities such as shell fragments or excessive fines. These impurities weaken the paste-aggregate bond and therefore strongly influence the tensile behavior of concrete. Additionally, due to the slower hydration rate at high slag contents, chloride binding with slag can alter the hydration process and delays strength development (Wang et al., 2023).

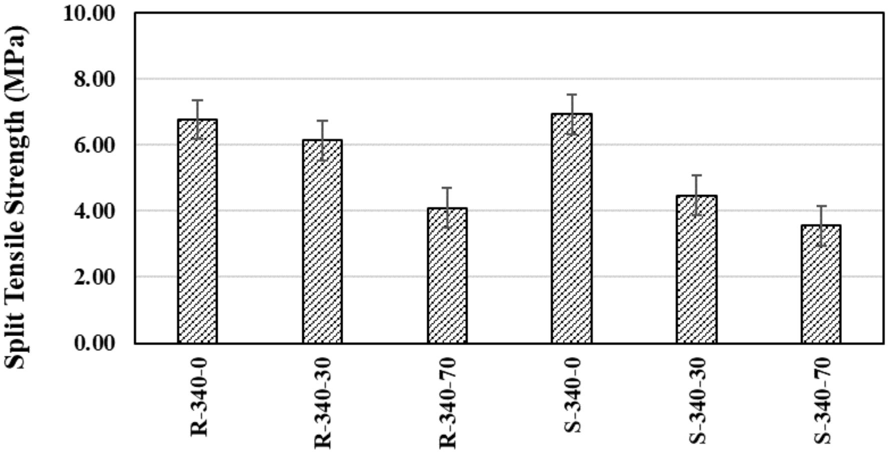


Figure 5. Split Tensile Strength

4. CONCLUSIONS

This study primarily investigates alternative materials that can replace traditional natural resources in concrete and help reduce their excessive consumption. On that note, this research attempted to study the feasibility of using alternative local resources by completely replacing natural coarse aggregate with recycled brick aggregate and by replacing river sand with sea sand as well. Moreover, ground granulated blast-furnace slag (GGBFS) was used as alternative cementitious material that replaced CEM TYPE I by 30% and 70%, respectively. The concluded test results are as follows:

- Fresh properties were evaluated through slump tests, results ranging from 83 mm to 113 mm. Slump value increases with increasing slag percentage in the concrete mix by improving flowability and reducing water demand. As a result, seawater with 70% slag content shows the highest slump value of 112.5 mm.
- In UPV test, most of the specimens were within medium to good quality that confirmed satisfactory internal concrete quality across all mixes. Slag refines the pore structure of the mixes, reducing total porosity and improving overall durability of concrete made with recycled brick aggregates.
- Concrete made with fully CEM TYPE I and sea sand demonstrates greater early-age (7-day) strength compared to river sand concrete, which can be attributed to the accelerating influence of chloride ions on initial cement hydration.
- Compressive strength peaks at 30% slag for both river sand and sea sand mixes, and compressive strength declines at 70% slag for both river sand and sea sand mixes.
- Mixes of river sand produced higher tensile strength than sea sand concrete across all slag replacement levels.

DECLARATIONS OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the authors used ChatGPT, QuillBot and Grammarly in order to improve language and readability. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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