Journal of Engineering Science and Technology Review 16 (4) (2023) 196 - 204

Research Article

JOURNAL OF
Engineering Science
and Technology Review

www.jestr.org

Development of Sustainable Concrete from Blast Furnace Slag and Recycled Concrete Sand

Poonam* **and V.P Singh**

National Institute of Technology, (Civil Engineering Department), Kurukshetra (Haryana), India

Received 16 March 2023; Accepted 26 June 2023

Abstract

In recent years, higher demand for urbanization has led to more materials and assets. In the construction industry, the use of concrete is increasing day to day. But the problem is its higher cost and leads to CO2 emission. The application of waste materials in cement and sand replacement is the main area of concern. In this study, the behavior of normal concrete (M25) cast with a mixture of blast furnace slag aggregate (BFSA) and fine aggregate (FA) replacement by 0, 5, 15, 25, 35, and 50% as coarse aggregate (CA) and recycled concrete sand (RCS) with 0, 10, 25, 50, 75, and 100%, respectively. The workability, compressive strength (CS), splitting tensile strength (STS) and flexural strength (FS), water absorption, and air permeability have been evaluated. It has been confirmed that an increase in replaced content up to 100 % reduces the CS of concrete, but; at the 35% replacement, it shows good performance for BFSA. Substitution of FA with RCS at varying amounts has a detrimental impact on the concrete strength. Concrete containing RCS at 25% sand replacement has more excellent CS than the control mix.

Keywords: Blast Furnace Slag Aggregate, Recycled Concrete Sand, Waste Material Concrete.

---

1. Introduction

Recently, environmental pollution increased dramatically, creating problems for human and animal life. Also, industrial, domestic, and agricultural waste significantly contribute to massive amounts of solid waste (SW) development. Using natural techniques with a systematic method is necessary to overcome SW.

The waste product obtained from iron industries is blast furnace slag (BFS), Silica fume (SF), red mud, and other recycled waste. More than four hundred million tonnes of slag are generated annually by industries. The rising demand for steel and iron across industries has led to a rise in slag production. Slag production is being discarded in unsafe ways in landfills and urban areas, negatively affecting the environment [1]–[3]. Researchers have been looking into using slag in different forms in concrete mixtures to reduce environmental contamination caused by slag [4], [5].

In a fast-growing country like India, it will become more necessary to utilize waste materials effectively in a better manner because of the limited resources. It will help reduce the burden on natural resources while reducing the cost of the projects. Increasing development, strict environmental regulations, and the over-exploitation of natural resources have recently demanded using Construction and demolition (C&D) waste as aggregate for construction activities [6]–[8].

So far, using C&D waste in fresh concrete has significantly impacted its durability and strength [3–6]. The limited application of C&D waste as FA replacement is primarily due to its inferior properties, such as its higher water absorption capacity, lower density, and poor grading.

Several investigations have been conducted on the problem of C&D wastes application to concrete, as reflected in the literature published studies [9]–[12]. C&D waste in concrete is termed 'recycled materials concrete (RMC).'

The RMC behavior is determined mainly by the amount of RMC present and its overall strength. It has been shown that using RMC as a replacement for natural aggregate (NA) has some positive or negative effects on the concrete CS [13]–[18]. Furthermore, It has also been found that as the substitution amount of RMC in the substantial increases, the mechanical and durability of RMC are negatively impacted because; the water absorption of RMC is significantly higher than the normal concrete (NC) [19]–[24]. Variation in RMC concentration also indirectly affects other properties, such as drying shrinkage and creep coefficients [25]–[27].

BFSA, red mud, Fly ash, silica fume (SF), metakaolin, and rice husk ash are the industrial by-products that different researchers have used. Researchers have used it as cement replacement to improve concrete strength; due to; latent hydraulic properties, the CS increased at an early stage, and FS at later age showed better results [28]–[31].
The treatment of recycled materials with different parameters is considered, as changing its replacement, treatment of materials, or another method by using chemicals to improve the mechanical and durability property of RMC.

In this study, the behavior of normal concrete (NC) made with M25, a mixture of (BFSA) by 0, 5, 15, 25, 35, and 50% as coarse aggregate (CA) and recycled concrete sand (RCS) with 0, 10, 25, 50, 75, and 100%, as fine aggregate (FA) replacement has been carried out. Experiments have been conducted to evaluate Workability, CS, STS, FS, and water absorption.

All testing is performed as per Indian standards. Among the procedures for evaluating the hardened concrete condition is a compression test on cube specimens, as specified by Indian norms. SEM is used to do a topographic and compositional study on samples. Table 1 describes the different ordinary Portland cement (OPC) properties.

---

*E-mail address: poonamgoswami574@gmail.com

ISSN: 1791-2377 © 2023 School of Science, IHU. All rights reserved.

doi:10.25103/jestr.164.24

2. Research Significance

The waste material used as fine aggregate replacement in concrete is obtained from NIT Kurukshetra, from a concrete laboratory. The waste obtained from concrete specimen testing in the lab has been used as FA replacement, and the BFSA replaces CA.

RMC quality depends upon aggregate properties like aggregate quality, size, and texture. The aggregate size, texture, and quality affect concrete CS and uniformity variation [46]. The use of recycled concrete block waste as RCS to replacement of FA and RMC has been studied poorly. So, it is important to review the consequences of RCS and BFSA on concrete strength and to determine whether waste-material concrete is stronger, weaker, or equivalent to NC.

3. Experimental Detail

3.1.1 Cement

This study used 43-grade OPC cement conforming to IS: 8112 [32] and BFSA collected from Ambala city, India. According to previous literature, the standard laboratory tests have been carried out to determine various properties: IS 456-2000 [32] and IS 10262-2009 [33] are presented in Table 1.

Table 1. OPC Properties

Property	Results		
Normal consistency (%)	28%		
Soundness	2.5		
Fineness (%)	2		
Initial setting time (minutes)	126		
Final setting time (minutes)	243		
Specific gravity	3.19		
CS (MPa)	3 days	7 days	28 days
	26.6	34.23	45.60

3.1.2 Aggregates

Natural fine aggregate and coarse aggregates were procured from locally available markets, and grading analysis was conducted per IS: 383[34], with the results displayed in table 2 and table 3, respectively. Property like the Flakiness index, Elongation index, Specific gravity, Impact value, Bulk density, and Crushing value were calculated using the standards established by IS: 2386 (Part-III and IV) [35]. The blast furnace slag was ordered online from the Indiamart site and converted into a coarse aggregate shape with the help of a jaw crusher. For making RCS, already tested concrete specimens dumped near the concrete lab were collected. With the help of a hammer, these were crushed into small aggregates, and after that, with the help of the jaw crusher, it converted into the RCS , for similar Fineness modulus, sieve analysis has been carried out. Fig. 1 describes the process of Making BFSA and RCS.

Table 2. Mechanical properties of NA and BFSA

Property	NA	BFSA
Flakiness index (%)	15.39	7.35
Elongation index (%)	10.31	18.65
Specific gravity	2.67	2.58
Impact value (%)	9.60	17.30
Bulk density(loose) (kg/m^3)	1485	1310
Bulk density(compact) (kg/m^3)	1565	1417
Los Angeles abrasion resistance (%)	22.56	35.45
Crushing value (%)	20.10	12.53

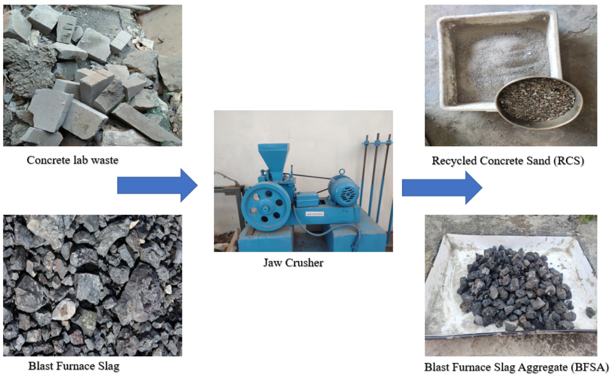


Fig. 1. Making process of BFSA and RCS.

Table 3. Mechanical properties of FA and RCS

Property	FA	RCS
Fineness modulus	2.38	2.38
Specific gravity	2.65	2.51
Bulk density (loose) (kg/m^3)	1545	1517
Bulk density (compact) (kg/m^3)	1685	1619
Zone	II	II

The test results for the BFSA, FA, and RCS chemical properties are listed in Table 4. Table 4 presents the chemical presence in binders, which reveals the percentage age of lime (CaO), silica (SiO_2), and alumina (Al_2O_3).

Table 4. Chemical presences in binders

S.No.	Chemical composition (wt %)	Fine aggregate (%)	Recycled Fine Aggregate (%)	Blast Furnace Slag (Coarse Aggregate) (%)
1	CaO	4.82	27.69	25.34
2	SiO_2	69.87	51.38	43.89
3	Al_2O_3	11.87	8.71	10.42
4	Fe_2O_3	5.56	4.53	11.88
5	MgO	2.07	1.85	4.33
6	Na_2O	1.28	1.01	0.56
7	K_2O	2.97	2.16	1.47
8	SO_3	0.19	1.4	0.35
9	LOI	1.37	1.27	1.76

3.1.3 Water

Concrete was cast using regular tap water purified in this experiment to remove harmful substances following IS: 10500-2012 [36].

4. Concrete Mixes Design

Twenty-four batches of concrete, with a control batch, were designed to achieve maximum strength, As per IS 10262-2009 [33]. In this study, the behavior of NC (M25) made with a mixture of blast furnace slag aggregate (BFSA) by 0, 5, 15, 25, 35, and 50% as coarse aggregate (CA) and Recycled concrete sand (RCS) with 0, 10, 25, 50, 75, and 100%, as fine aggregate (FA) replacement has been carried out.

The aggregates were assumed to be saturated surface dry for all mix designs. The effective water content is fixed for all the mixtures. But for RCS, additional water is added to achieve the required slump. Concrete mixes with varying percentages of RCA and BFSA have been described in Table 5.

Table 5. Concrete mixes with varying percentages of RCA and BFSA

BFSA as CA	**C (kg/m^3)**	**CA (kg/m^3)**	**FA (kg/m^3)**	**W (kg/m^3)**	**Extra water (kg/m^3) (%)**	**BFSA (kg/m^3)**
0BFSA28	342	711.4	1174	153.9	-	0
5BFSA28	342	675.81	1174	153.9	1	35.569
15BFSA28	342	640.24	1174	153.9	3	71.138
25BFSA28	342	533.54	1174	153.9	5	177.845
35BFSA28	342	462.4	1174	153.9	6	248.983
50BFSA28	342	355.69	1174	153.9	8	355.69
0BFSA56	342	711.38	1174	153.9	-	0
5BFSA56	342	675.81	1174	153.9	1	35.569
15BFSA56	342	640.24	1174	153.9	3	71.138
25BFSA56	342	533.54	1174	153.9	5	177.845
35BFSA56	342	462.4	1174	153.9	6	248.983
50BFSA56	342	355.69	1174	153.9	8	355.69
RCS as FA	**C (kg/m^3)**	**CA (kg/m^3)**	**FA (kg/m^3)**	**W (kg/m^3)**	**Extra water (kg/m^3) (%)**	**RCS (kg/m^3)**
0RCS28	342	711.4	1174	153.9	-	0
10RCS28	342	701.4	1057	153.9	2	117.4
25RCS28	342	686.4	880.5	153.9	4	293.5
50RCS28	342	661.4	587	153.9	6	587
75RCS28	342	636.4	293.5	153.9	8	880.5
100RCS28	342	611.4	0	153.9	9	1174
0RCS56	342	711.4	1174	153.9	-	0
10RCS56	342	701.4	1057	153.9	2	117.4
25RCS56	342	686.4	880.5	153.9	4	293.5
50RCS56	342	661.4	587	153.9	6	587
75RCS56	342	636.4	293.5	153.9	8	880.5
100RCS56	342	611.4	0	153.9	9	1174

C= cement, CA=coarse aggregate, FA= fine aggregate, W=water

5. Curing and Casting the Specimen

The binder, FA, and CA were slowly mixed in a concrete mixer for two minutes. The concrete mixer started for two minutes, and water was added to the dry materials to get the desired workable consistency. After a suitable mixture, the fresh concrete was poured into the slump cone, and its value was measured. After achieving an appropriate mix, the freshly mixed concrete was poured into various shapes, including cubes, cylinders, and prisms, has been shown in Table 6. The specimens were removed after 24 hours from their mould and submerged in water at 27°C for 28 and 56 days.

According to Indian standard codes of practice, tests were performed on specimens to assess the concrete CS, STS, FS, and water absorption.

Table 6. The details of specimen property, size, and age at the test with method

Property	Size of specimen	Test standard
CS (28d, 56d)	150×150×150 mm cubes	IS:516 [37]
FS	100×100×500 mm prism	IS:516 [37]
STS	150×300 mm cylinders	IS:5816 [38]
Water absorption	150×150×150 mm cubes	IS: 1124 [39]

The compressive force was applied to standard 150 mm cubes using a compression testing machine (CTM) with a capacity of 2000 kN to conduct the compressive strength test. The load rate has been maintained at 14 N/mm/min for 28 and 56 days for CS. Similarly, the concrete was subjected to an STS test using cylindrical specimens with a 150 mm diameter and 300 mm height in a CTM with a 2000 kN capacity at 28 and 56 days. Also, 100 mm × 100 mm × 500 mm prisms were used for a 2000 kN CTM FS test after 28 and 56 days. For the durability test, water absorption of the concrete mixtures was measured using standard 150 ×150 ×150 mm cubes. Each test was conducted on three samples, and the average results were considered.

6. Results

6.1 Workability of concrete

Fig. 2 shows the difference in the slump of concrete mixtures, including varying amounts of RCS and BFSA. From the graph, it can be concluded that the slump values for concrete mixtures containing 0, 10, 25, 50, 75, and 100 RCS are 78, 81, 92, 94, 106, and 107, respectively, for 28 days. Similarly, 0, 10, 25, 50, 75, and 100% RCS are 73, 79, 85, 91, 96, and 106 for 56 days. It means that the slump values of concrete mixes increase as the amount of RCA within them increases. The slump values for concrete mixtures containing 0, 5, 15, 25, 35, and 50 BFSA are 75, 79, 84, 90, 97, and 106 at 28 days and 78, 82, 91, 94, 100, and 102 at 56 days, respectively.

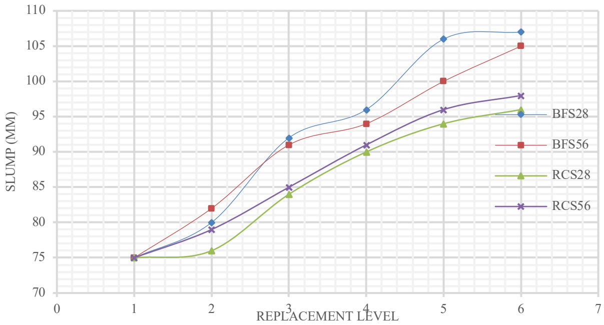
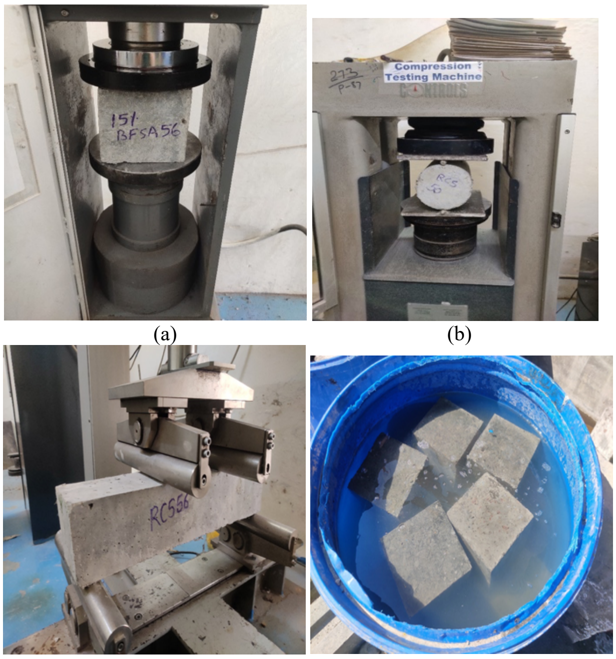


Fig. 2. Workability of concrete with BFA and RCS at 28, 56d.

Slump values tend to be higher in RCS because there is more free water initially. However, RCA absorbs all of the additional water in the final. The stated excess water cannot be utilized in the concrete mixing process. The rough surface of the artificial aggregate increases its surface area, contributing to the aggregate's angular appearance and low fluidity. In addition, it could be because BFSA absorbs more water than NA compared to RCS [40].



(a) (b)

(c) (d)

Fig. 3. Various test setups a) Compression test setup, b) Split Tensile Test setup, c) Flexural test setup and d) Water absorption

6.2 Compressive strength

Fig. 4 shows the CS behavior at 28 and 56 d for concrete with different RCS and GBFSA replacement levels. The CS of the Control mix at 28 and 56 days is 33.98 and 39.21 MPa, respectively, for BFSA with 5, 15, 25, 35, and 50% CA replacement by BFSA. After 28 days, the CS is 34.23, 35.84, 37.75, 41.78, and 31.65 MPa. Similarly, for BFSA with 5, 15, 25, 35, 45.73MPa, 48.36Mpa and 35.91MPa and 50% CA replacement by BFSA, After 56 days, the CS is 41.86, 43.59 MPa, respectively.

The CS of the above mixes for BFSA replacement increased from 33.98 MPa (Control mix) to 34.23 MPa (0.73%), 35.84 MPa (5.47%), 37.75MPa(11.09%), and 41.78MPa (22.95%) and decreased for 31.65 MPa (6.85%) at 28 days.

The CS of the above mixes for BFSA replacement increased from 39.21 MPa (Control mix) to 41.86 MPa (6.75%), 43.59 MPa (11.17%), 45.73 MPa (16.62%), and 48.36 MPa (23.33%) and decreased for 35.91 MPa (8.41%) at 56 days.

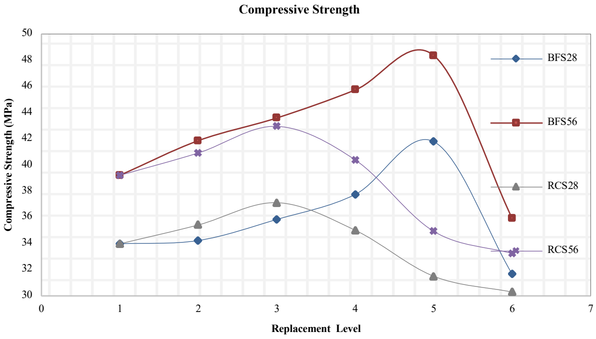


Fig. 4. CS of concrete with BFSA at 28, 56d

The CS of the above mixes for RCS replacement increased from 33.98 MPa (Control mix) to 35.42 MPa (4.23%), 37.12 MPa (9.28%), 35.01 MPa (3.03%), and decreased from control mix to 31.5 MPa (7.29%) and 30.29 MPa (10.85%) at 28 days.

The CS of the above mixes for RCS replacement increased from 33.98 MPa (Control mix) to 40.92 MPa (4.36%), 42.95 MPa (9.53%), 40.38 MPa (2.98%), and decreased from control mix to 34.93 MPa (10.91%) and 33.23 MPa (15.25%) at 56 days. Factors influencing the CS of RCS and BFSA include RCA's physical and mechanical characteristics, the rate at which RCS and BFSA are replaced, and the w/c ratio [8].

Some researchers believe that the decline in CS can be explained by the higher rate of RCS replacement and the inferior quality of RCS compared to NA. From the results above, it is clear that at 28 and 56 days, the concrete mixes (50BFSA28, 50BFSA56) showed lower compressive strengths than the control mix for BFSA replacement. This decrease is due to a smaller strength gain from the increased BFSA component and a more significant loss due to the reduced cement percentage. This decrease is mainly attributable to the angular shape of the artificial aggregate and the increased surface area induced by the surface's roughness (Fig. 3b), both of which contribute to the aggregate's low fluidity. Moreover, it may result from the greater water absorption of BFSA relative to natural aggregation. [ref]. From the results above, it is clear that at 28 and 56 days, the concrete mixes (75RCS28, 75RCS56, and 100RCS28 and 100RCS56) showed lower compressive strengths than the control mix for RCS replacement. As a result, the interaction between old mortar and new cement paste often reduces the strength of concrete created with recycled material [41]–[43]. Hence, the complex interaction behavior of RCS must be addressed. However, each mixture meets the design strength criteria on all curing days, but higher replacement leads to a lower w/c ratio [44].

Results show that CS increased up to 23% for 35% replacement of BFSA as CA and approximately 9% increased with RCS replacement compared to the control concrete mix. Since they use waste resources most while having the least damaging effect on the environment, BSF35 and RCS25 are the most eco-friendly strong mixes.

6.3 Split tensile strength

Fig. 5 shows the **STS** behavior for concrete at 28 and 56 days with different RCS and BFSA replacement levels. The STS of the Control mix at 28 and 56 d is 3.4 and 3.7 MPa for BFSA with 5, 15,25, 35, and 50% CA replacement by

BFSA. After 28 days, the value obtained for STS is 3.7, 3.9, 4, 3.8, and 3.2 MPa. The value was calculated with BFSA 5, 15, 25, 35, and 50% CA replacement by BFSA. After 56 days, the STS value obtained is 3.9, 4.1, 4.2, 4.4, and 3.5 MPa, respectively.

The STS of the above mixes for BFSA replacement increased from 3.4 MPa (Control mix) to 3.7 MPa (8.82%), 3.9 MPa (14.70%), 4 MPa(17.64%), and 3.8 MPa (11.76%) and decreased for 3.2 MPa (5.88%) at 28 days.

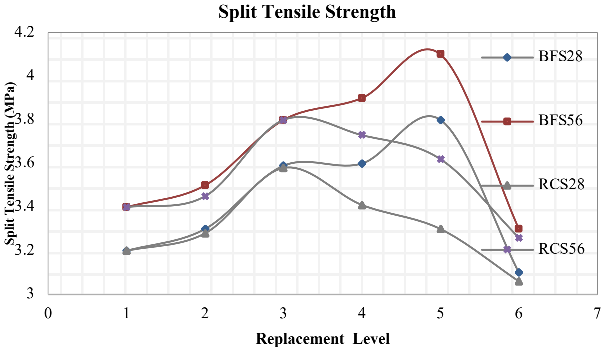


Fig. 5. STS of concrete with BFSA at 28, 56d.

The STS of the above mixes for BFSA replacement increased from 3.7 MPa (Control mix) to 3.9 MPa (5.4%), 4.1MPa (10.81%), 4.2 MPa (13.5%), and 4.4 MPa (18.9%) and decreased for 3.5 MPa (5.4%) at 56 days.

The STS of the above mixes for RCS replacement increased from 3.4MPa (Control mix) to 3.5 MPa (2.9%), 4MPa (17.6%), 3.8 MPa (11.7%), and decreased from control mix to 3.3 MPa (2.9%) and 3.1 MPa (8.8%) at 28 days.

The STS of the above mixes for RCS replacement increased from 3.7MPa (Control mix) to 3.8 MPa (2.7%), 4.2 MPa (13.5%), 4.1 MPa (10.8%), and decreased from control mix to 3.6 MPa (2.7%) and 3.5 MPa (5.4%) at 56 days. Factors influencing the STS of RCS and BFSA include RCA's physical and mechanical characteristics, the rate at which RCS and BFSA are replaced, and the w/c ratio [8].

The STS of concretes made with RCS is lower than that of concretes made with crusher sand, according to studies [9], [10], [23], [48], and [53]. It may be because the interfacial zone of the old attached mortar is weaker or because the quality of RCS is poorer than that of NA. As such, it's important to note that the current study's results are superior to those of earlier research because of the higher quality RCS employed.

Results show that STS increased up to 17-18% for 35% replacement of BFSA as CA and approximately 13-17% increased with RCS replacement compared to the control concrete mix. Since they use waste resources most while having the least negative effect on the environment, BSF35 and RCS25 are the most eco-friendly strong mixes.

6.4 Flexural strength

Fig. 6 shows the FS behavior at 28 and 56 d for concrete with different RCS and GBFSA replacement levels. The FS of the Control mix at 28 and 56 d is 3.2 and 3.4 MPa. for BFSA with 5, 15, 25, 35, and 50% CA replacement by BFSA. After 28 days, the FS is 3.3, 3.59, 3.6, 3.8, and 3.1 MPa, similarly for BFSA with 5, 15, 25, 35, and 50% CA replacement by BFSA. After 56 days, the values obtained for CS are 3.5, 3.8, 3.9, 4.1, and 3.3 MPa, respectively.

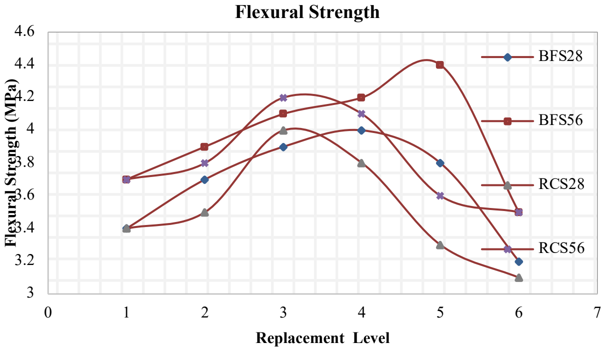


Fig. 6. FS of concrete with BFSA at 28, 56d.

The FS of the above mixes for BFSA replacement increased from 3.2 MPa (Control mix) to 3.3 MPa (3.12%), 3.59 MPa (12.18%), 3.6 MPa(12.5%), and 3.8 MPa (18.75%) and decreased for 3.1 MPa (3.21%) at 28 days.

The FS of the above mixes for BFSA replacement increased from 3.4 MPa (Control mix) to 3.5 MPa (2.94%), 3.8 MPa (11.76%), 3.9 MPa (14.7%), and 4.1 MPa (20.58%) and decreased for 3.3 MPa (2.94%) at 56 days.

The FS of the above mixes for RCS replacement increased from 3.2 MPa (Control mix) to 3.28 MPa (2.5%), 3.58 MPa (11.8%), 3.41 MPa (6.56%), and 3.3MPa (3.12%) and decreased for 3.06 MPa (4.37%) at 28 days.

The FS of the above mixes for RCS replacement increased from 3.4 MPa (Control mix) to 3.45 MPa (1.47%), 3.8 MPa (11.7%), 3.73 MPa (9.7%), and 3.62 MPa (6.47%) decreased from control mix to 3.26 MPa (4.11%) at 56 days. Factors influencing the CS of RCS and BFSA include RCA's physical and mechanical characteristics, the rate at which RCS and BFSA are replaced, and the w/c ratio [44].

Results show that FS increased up to 18-20% for 35% replacement of BFSA as CA, and approximately 11% increased with RCS replacement compared to the control concrete mix. Since they use waste resources most while having the least negative effect on the environment, BSF35 and RCS25 are the most eco-friendly flexural strong mixes.

An increase in the replacement percentage of CA indicates a slight reduction in strength at a higher level. This could be due to the porous aggregate's low cracking resistance and other weak qualities, such as a relatively low compressive strength. Reduced flexural strength resulted from the aggregate particles that were measures of strength. Superior results were seen in the concrete with a higher compressive strength [40].

7. Comparative Analysis

7.1 Relation between split tensile and compressive strength of concrete mixes.

The correlation between CS and STS of concrete mixes is shown in Fig. 7. This provides an analysis of their relationship. For converting Compressive strength to the true cylinder CS a correction factor of 0.8 is used. Regression analysis can determine that the relationship between concrete CS and its STS is for BFSA replacement.

$$f_t = 0.6419\sqrt{f_{ck}} \quad (1)$$

Regression analysis can determine that the relationship between concrete CS and its STS is for RCS replacement.

$$f_t = 0.6353\sqrt{f_{ck}} \quad (2)$$

where, f_{ck} = concrete CS and f_t= STS.

A formula has been proposed to estimate the STS from the compressive strength.

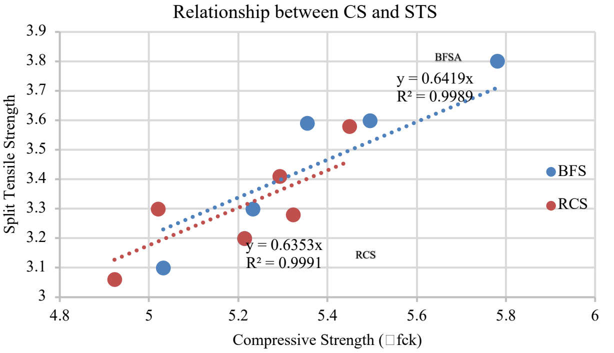


Fig. 7. Relation between CS and STS of concrete mixes

7.2 Relation between flexural and compressive strength of concrete mixes.

The correlation between CS and FS of concrete mixes, as shown in Fig. 8, provides an analysis of their relationship. For converting Compressive strength to the true cylinder CS a correction factor of 0.8 is used. Regression analysis can determine that the relationship between concrete CS and its FS is for BFSA replacement.

$$f_{cr} = 0.6855\sqrt{f_{ck}} \tag{3}$$

Regression analysis can determine that the relationship between concrete CS and its STS is for RCS replacement.

$$f_{cr} = 0.6768\sqrt{f_{ck}} \tag{4}$$

where, f_{ck} = the concrete CS and f_{cr} = FS. The formula has been proposed to estimate the STS from the compressive strength,

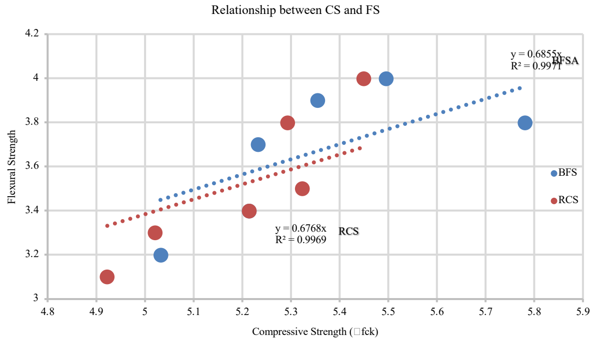


Fig. 8. Relation between CS and FS of concrete mixes

7.3 Comparison among CS, STS, and FS

Concrete mixes with variable replacement of BFSA and RCS exhibit variation in CS, STS, and FS at 28 d, as compared to the equivalent values for the control mix, as shown in Fig. 9. Figure, It can see that the strength is decreased to CS, then STS and followed FS. As was previously discussed, the rough surface of the BFSA and the finer particles of the RCS may be responsible for this improvement in the microstructure of the ITZ and the binding strength between the mortar and the RCS.

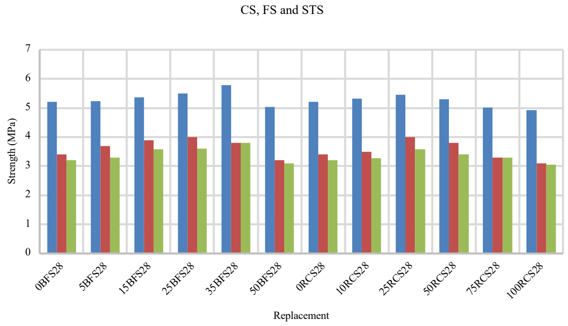


Fig. 9. Concrete CS, FS, and STS at various replacement

8. Durability test

8.1 Water Absorption

Fig. 10 describes concrete mixes made with varying amounts of BFSA and RCS replacement over 28 days for water absorption. It is clear from the Fig. 10 that the BFSA by 0, 5, 15, 25, 35, and 50% as CA replacement increases water absorption from 3.08%, Normal Mix) to 4.11, 4.31, 4.53, 5.02, and 5.8%. RCS with 10, 25, 50, 75, and 100%, as FA replacement increases water absorption from 3.08% (Normal Mix) to 4.25, 4.46, 4.61, 4.78, and 5.94 %, respectively.

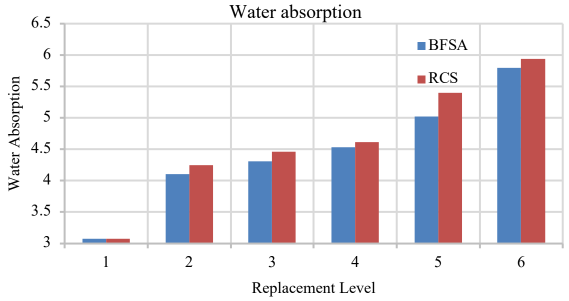


Fig. 10. Water Absorption with different amounts of BFSA and RCS replacement

As a result, the percentage increases in water absorption capacity from the NA for concrete mixtures containing 5, 15, 25, 35, and 50% BFSA are 33.44, 39.44, 39.93, 47.07, 62.98, and 88.31%, respectively. Similarly, for FA concrete mixtures containing 10, 25, 50, 75, and 100%, RCS is 37.98, 44.80, 49.67, 55.19, and 92.85%, respectively. The ability to absorb water for RCS increases higher when added to BFSA. However, this is primarily because of increased RCS content or more surface area, while BFSA has minimal effect.

8.2 Permeability test

It's the quickest and cheapest method to evaluate permeability at the site also. The AUTOCLAM permeability system shown in Fig. 11 was assembled and utilized to test plate specimens for air permeability. A regular base ring was used to separate the testing environment from the surface of the cast specimen.

A regular base ring was used to separate the testing environment from the surface of the cast specimen. The air permeability test was initiated by manually applying pressure inside the autoclam system using a syringe attached to the system's base. The air permeability test began automatically after pressure inside the testing instrument hit 500 mbar, and the subsequent 15 minutes of pressure drops were recorded.

Fig. 11. The AUTOCLAM permeability system

The microstructure of a cement-based matrix directly affects its durability performance, which the permeability, absorption, movement, and diffusion of ions may measure. The current study recorded the air permeability (water absorption) performance of several BFSA, and RCS mixes after 56 days of water curing using the AUTOCLAM permeability system.

Fig. 12 shows the air permeability values of BFSA and RCS mixes following 56 days of water curing. For the control, mix permeability is 0.0021 Ln(mbar)/min, and with replacement of for concrete mixtures containing 5, 15, 25, 35, and 50% BFSA 0.0023, 0.0029,0.0031,0.0035, and 0.0038 Ln(mbar)/min respectively. Similarly, for FA concrete mixtures containing 10, 25, 50, 75, and 100%, RCS is .002, .0019,.0016,.0014, and .0011 Ln(mbar)/min, respectively.

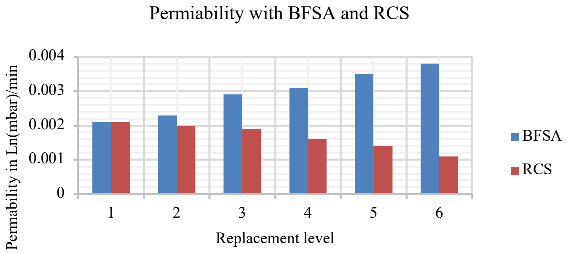


Fig. 12. Air permeability with different amounts of BFSA and RCS replacement

The permeability of the above mixes for BFSA replacement increased from .0021 Ln(mbar)/min (Control mix) to 0.0023(9.52%), .0029 (38.09%), .0031 (47.61%), and .0035 (66.6%) and 0.0038 (80.92%) Ln(mbar)/min, respectively. The increment in the permeability with the addition of BFSA increased due to the higher porous media present in BFSA due to the increased number of microvoids.

Similarly, a downfall in the permeability was recorded for RCS replacement form from .0021 Ln(mbar)/min (Control mix) to 0.0020(4.76%), .0019 (9.52%), .0016 (23.8%), and .0014 (33.3%) and 0.0011 (47.61%) Ln(mbar)/min, respectively. While describing the permeability of concrete, it is said to decrease with an increment in RCS percentage due to its filler effects.

9. Conclusion

This work aims to minimize the environmental effect by identifying alternative methods to recycle construction and demolition (C&D) waste and concrete construction material. To investigate the properties and the impact of RCS and BFS of concrete with different mixes. The possible outcomes are as follows from the experiment results:

The slump values of concrete mixes increase as the amount of RCA within these mixes increases. The slump values for concrete mixtures containing 0, 5, 15, 25, 35, and 50 BFSA are 75, 79, 84, 90, 97, and 106 (28d) and 78, 82, 91, 94, 100, and 102 (56d), respectively. Slump values tend to be higher in RCS because there is more free water initially. However, RCA absorbs all of the additional water in the final.

Results show that CS increased up to 23% for 35% replacement of BFSA as CA and approximately 9% increased with RCS replacement compared to the control concrete mix.

Results show that STS increased up to 17-18% for 35% replacement of BFSA as CA and approximately 13-17% increased with RCS replacement compared to the control concrete mix.

Results show that FS increased up to 18-20% for 35% replacement of BFSA as CA, and approximately 11% increased with RCS replacement compared to the control concrete mix.

Since they use waste resources most while having the least negative effect on the environment, BSF35 and RCS25 are the most eco-friendly strong mixes.

For the control, mix permeability is 0.0021 Ln(mbar)/min, and with replacement of for concrete mixtures containing 5, 15, 25, 35, and 50% BFSA 0.0023, 0.0029,0.0031,0.0035, and 0.0038 Ln(mbar)/min respectively. Similarly, for FA concrete mixtures containing 10, 25, 50, 75, and 100%, RCS is .002, .0019,.0016,.0014, and .0011 Ln(mbar)/min, respectively.

This is an Open Access article distributed under the terms of the Creative Commons Attribution License.

References

[1] B. Pradhan, S. Chand, S. Chand, P. R. Rout, and S. K. Naik, “Emerging groundwater contaminants: A comprehensive review on their health hazards and remediation technologies,” *Groundw. Sustain. Dev.*, vol. 20, p. 100868, Feb. 2023, doi: 10.1016/j.gsd.2022.100868.

[2] B. G. Miller, “The Effect of Coal Usage on Human Health and the Environment,” in *Clean Coal Engineering Technology*, Elsevier, 2011, pp. 85–132. doi: 10.1016/B978-1-85617-710-8.00004-2.

[3] Babita, Saini and Pulkit, Kavendra, *Effect of stone slurry & recycled aggregate on properties of concrete Waste management*. LAP LAMBERT Academic Publishing, 2018.

[4] S. Bolan *et al.*, “Review on distribution, fate, and management of potentially toxic elements in incinerated medical wastes,” *Environ. Pollut.*, vol. 321, p. 121080, Mar. 2023, doi: 10.1016/j.envpol.2023.121080.

[5] J. Koelmel, M. N. V. Prasad, G. Velvizhi, S. K. Butti, and S. V. Mohan, “Metalliferous Waste in India and Knowledge Explosion in Metal Recovery Techniques and Processes for the Prevention of Pollution,” in

Environmental Materials and Waste, Elsevier, 2016, pp. 339–390. doi: 10.1016/B978-0-12-803837-6.00015-9.

[6] A. Agarwal, G. V. Ramana, M. Datta, N. K. Soni, and R. Satyakam, "Pullout behaviour of polymeric strips embedded in mixed recycled aggregate (MRA) from construction & demolition (C&D) waste – Effect of type of fill and compaction," *Geotext. Geomembr.*, vol. 51, no. 3, pp. 405–417, Jun. 2023, doi: 10.1016/j.geotexmem.2023.01.004.

[7] Y. (Shanko) A. Abera, "Performance of concrete materials containing recycled aggregate from construction and demolition waste," *Results Mater.*, vol. 14, p. 100278, Jun. 2022, doi: 10.1016/j.rinma.2022.100278.

[8] M. Bergonzoni, R. Melloni, and L. Botti, "Analysis of sustainable concrete obtained from the by-products of an industrial process and recycled aggregates from construction and demolition waste," *Procedia Comput. Sci.*, vol. 217, pp. 41–51, 2023, doi: 10.1016/j.procs.2022.12.200.

[9] J. J. Assaad, C. Mikhael, and R. Hanna, "Recycling of waste expanded polystyrene concrete in lightweight sandwich panels and structural applications," *Clean. Mater.*, vol. 4, p. 100095, Jun. 2022, doi: 10.1016/j.clema.2022.100095.

[10] H. Liu, Q. Li, and P. Wang, "Assessment of the engineering properties and economic advantage of recycled aggregate concrete developed from waste clay bricks and coconut shells," *J. Build. Eng.*, vol. 68, p. 106071, Jun. 2023, doi: 10.1016/j.jobe.2023.106071.

[11] W. Chen and R. Jin, "Recycled concrete for nonstructural applications," in *Recycled Concrete*, Elsevier, 2023, pp. 233–263. doi: 10.1016/B978-0-323-85210-4.00006-0.

[12] M. M. Ul Islam, J. Li, R. Roychand, M. Saberian, and F. Chen, "A comprehensive review on the application of renewable waste tire rubbers and fibers in sustainable concrete," *J. Clean. Prod.*, vol. 374, p. 133998, Nov. 2022, doi: 10.1016/j.jclepro.2022.133998.

[13] O. Gencel, A. Benli, O. Y. Bayraktar, G. Kaplan, M. Sutcu, and W. A. T. Elabade, "Effect of waste marble powder and rice husk ash on the microstructural, physico-mechanical and transport properties of foam concretes exposed to high temperatures and freeze–thaw cycles," *Constr. Build. Mater.*, vol. 291, p. 123374, Jul. 2021, doi: 10.1016/j.conbuildmat.2021.123374.

[14] V. Quan Tran, V. Quoc Dang, and L. Si Ho, "Evaluating compressive strength of concrete made with recycled concrete aggregates using machine learning approach," *Constr. Build. Mater.*, vol. 323, p. 126578, Mar. 2022, doi: 10.1016/j.conbuildmat.2022.126578.

[15] I. Patra, G. R. L. Al-Awsi, Y. M. Hasan, and S. S. K. Almotlaq, "Mechanical properties of concrete containing recycled aggregate from construction waste," *Sustain. Energy Technol. Assess.*, vol. 53, p. 102722, Oct. 2022, doi: 10.1016/j.seta.2022.102722.

[16] J. Yan *et al.*, "Influence of nano-attapulgite on compressive strength and microstructure of recycled aggregate concrete," *Cem. Concr. Compos.*, vol. 134, p. 104788, Nov. 2022, doi: 10.1016/j.cemconcomp.2022.104788.

[17] X. Wang, C. S. Chin, and J. Xia, "Study on the properties variation of recycled concrete paving block containing multiple waste materials," *Case Stud. Constr. Mater.*, vol. 18, p. e01803, Jul. 2023, doi: 10.1016/j.cscm.2022.e01803.

[18] L. Peng *et al.*, "Enhancing the corrosion resistance of recycled aggregate concrete by incorporating waste glass powder," *Cem. Concr. Compos.*, vol. 137, p. 104909, Mar. 2023, doi: 10.1016/j.cemconcomp.2022.104909.

[19] O. Şimşek, H. Pourghadri Sefidehkhan, and H. S. Gökçe, "Performance of fly ash-blended Portland cement concrete developed by using fine or coarse recycled concrete aggregate," *Constr. Build. Mater.*, vol. 357, p. 129431, Nov. 2022, doi: 10.1016/j.conbuildmat.2022.129431.

[20] J. Xiao, H. Zhang, S. Zou, Z. Duan, and Y. Ma, "Developing recycled foamed concrete for engineered material arresting system," *J. Build. Eng.*, vol. 53, p. 104555, Aug. 2022, doi: 10.1016/j.jobe.2022.104555.

[21] J. Yang *et al.*, "Feasibility of recycled aggregates modified with a compound method involving sodium silicate and silane as permeable concrete aggregates," *Constr. Build. Mater.*, vol. 361, p. 129747, Dec. 2022, doi: 10.1016/j.conbuildmat.2022.129747.

[22] T. Meng, H. Yu, Y. Zhao, and S. Ruan, "Strength/Service life-oriented environmental assessment of normal and recycled concrete with nano-SiO2 in a natural and a marine environment: A pioneer case study in Zhejiang Province," *J. Build. Eng.*, vol. 64, p. 105623, Apr. 2023, doi: 10.1016/j.jobe.2022.105623.

[23] T. M. Tung, O. E. Babalola, and D.-H. Le, "Experimental investigation of the performance of ground granulated blast furnace slag blended recycled aggregate concrete exposed to elevated temperatures," *Clean. Waste Syst.*, vol. 4, p. 100069, Apr. 2023, doi: 10.1016/j.clwas.2022.100069.

[24] M. I. Mostazid and Y. Sakai, "Effect of heat treatment on mechanical behavior and scaling resistance of slag impregnated low strength recycled compacted concrete," *J. Build. Eng.*, vol. 68, p. 106084, Jun. 2023, doi: 10.1016/j.jobe.2023.106084.

[25] Z. Wang, Y. Liu, J. Tu, and Y. Gao, "Calculation analysis method to model the creep of recycled aggregate of thermal insulation concrete," *Constr. Build. Mater.*, vol. 331, p. 127229, May 2022, doi: 10.1016/j.conbuildmat.2022.127229.

[26] F. L. Gayarre, J. S. González, C. L.-C. Pérez, M. A. Serrano López, P. S. Ros, and G. Martínez-Barrera, "Shrinkage and creep in structural concrete with recycled brick aggregates," *Constr. Build. Mater.*, vol. 228, p. 116750, Dec. 2019, doi: 10.1016/j.conbuildmat.2019.116750.

[27] X. Wang, W. Wang, J. Huang, Z. Wang, S. Ma, and Y. Liu, "Relationship between internal humidity and drying shrinkage of recycled aggregate thermal insulation concrete considering recycled aggregate content," *Constr. Build. Mater.*, vol. 355, p. 129224, Nov. 2022, doi: 10.1016/j.conbuildmat.2022.129224.

[28] F. Zhu, C. Yang, and M. Miao, "Experimental study on the properties of polyvinyl alcohol fiber reinforced cementitious composites with super early strength," *Mater. Lett.*, vol. 330, p. 133264, Jan. 2023, doi: 10.1016/j.matlet.2022.133264.

[29] J. Goergens, R. Belli, C. Schulbert, and F. Goetz-Neunhoeffer, "Influence of different CA2/CA-ratios on hydration degree, AH3 content and flexural strength investigated for a binder formulation of calcium aluminate cement with calcite," *Cem. Concr. Res.*, vol. 165, p. 107090, Mar. 2023, doi: 10.1016/j.cemconres.2023.107090.

[30] H. E. Yücel, H. Ö. Öz, M. Güneş, and Y. Kaya, "Rheological properties, strength characteristics and flexural performances of engineered cementitious composites incorporating synthetic wollastonite microfibers with two different high aspect ratios," *Constr. Build. Mater.*, vol. 306, p. 124921, Nov. 2021, doi: 10.1016/j.conbuildmat.2021.124921.

[31] S. S. Solanke, P. Y. Pawade, and H. Ali Khan, "An experimental study on tensile as well as flexural strength of concrete by using sugarcane baggase ash & steel fiber," *Mater. Today Proc.*, vol. 60, pp. 627–637, 2022, doi: 10.1016/j.matpr.2022.02.129.

[32] Bureau of Indian Standards, "IS 456 Plain and Reinforced Concrete." Bureau of Indian Standards, New Delhi, 2020.

[33] Bureau of Indian Standard, "IS 10262 Guidelines for concrete mix design proportioning.” New Delhi, 2009.

[34] Bureau of Indian Standard, “IS 383 Specification for coarse and fine aggregates from Natural Sources for Concrete.” New Delhi, 1970.

[35] Bureau of Indian Standards, “IS 2386 (Part III) Method of Test for aggregate for concrete.” New Delhi, 2020.

[36] Bureau of Indian Standards, “IS 10500 Indian Standard Drinking Water Specification (Second Revision).” Bureau of Indian Standards, New Delhi.1999.

[37] ‚Bureau of Indian Standards, “IS 516 Hardened Concrete - Methods of Test.” Bureau of Indian Standards, New Delhi, 1959.

[38] Bureau of Indian Standards, “IS 5816 Splitting tensile strength of concrete- method of test.” Bureau of Indian Standards, New Delhi, 1999.

[39] Bureau of Indian Standards, “IS 1124 Method of test for determination of water absorption, apparent specific gravity and porosity of natural building stones.” Bureau of Indian Standards, New Delhi.1990.

[40] Q. Cao, U. Nawaz, X. Jiang, L. Zhang, and W. S. Ansari, “Effect of air-cooled blast furnace slag aggregate on mechanical properties of ultra-high-performance concrete,” *Case Stud. Constr. Mater.*, vol. 16, p. e01027, Jun. 2022, doi: 10.1016/j.cscm.2022.e01027.

[41] K. Pulkit, B. Saini, and H. D. Chalak, “Factors Affecting the Bond Between Substrate-Overlay Material. A Review,” *J. Eng. Sci. Technol. Rev.*, vol. 15, no. 6, pp. 55–69, Dec. 2022, doi: 10.25103/jestr.156.08.

[42] K. Pulkit, B. Saini, and H. D. Chalak, “Effect of various interface bond tests and their failure behavior on substrate and overlay concrete -A Review,” *Res. Eng. Struct. Mater.*, Oct. 2023, doi: 10.17515/resm2022.575me1103.

[43] K. Pulkit, B. Saini, and H. Chalak, “The influence of interfacial bond between substrate and overlay concrete by Bi-surface Shear Test and Split prism test,” *Res. Eng. Struct. Mater.*, Dec. 2023, doi: 10.17515/resm2023.797ma06x112.

[44] S. Ghorbani *et al.*, “Simultaneous effect of granite waste dust as partial replacement of cement and magnetized water on the properties of concrete exposed to NaCl and H_2SO_4 solutions,” *Constr. Build. Mater.*, vol. 288, p. 123064, Jun. 2021, doi: 10.1016/j.conbuildmat.2021.123064.