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Research Article

Sustainable Concrete Columns with GGBS and Industrial Sand: A Comparative Study on Destructive and Nondestructive Tests on Damaged Columns Strengthened with GFRP Jacketing

G. I. Gunarani,[1] **B. Karthikeyan**,[1] **A. Priyadharshini**,[1] **Senthil Kumaran Selvaraj**,[2] **S Jose**,[3] **D. Vincent Herald Wilson**,[3] **and Tezeta Moges Adane**[4]

[1]*SASTRA Deemed to be University, Thanjavur 613401, Tamil Nadu, India*
[2]*Department of Manufacturing Engineering, School of Mechanical Engineering (SMEC), Vellore Institute of Technology (VIT), Vellore 632014, Tamil Nadu, India*
[3]*School of Mechanical Engineering (SMEC), Vellore Institute of Technology (VIT), Vellore 632014, Tamil Nadu, India*
[4]*School of Civil Engineering, Engineering and Technology College Dilla University, P.O.Box. 419, Dilla, Ethiopia*

Correspondence should be addressed to Senthil Kumaran Selvaraj; senthilkumaranselvaraj82@gmail.com and Tezeta Moges Adane; tezetam@du.edu.et

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This paper presents the experimental investigation of the load-resisting characteristics of damaged columns repaired with glass reinforced polymer (GFRP) jacketing. The high-strength columns were made with ground granulated blast furnace slag (GGBS) used at 15%, 25%, and 35% as a partial substitute for cement. Cube specimens of size 100 mm × 100 mm × 100 mm and columns of size 600 mm × 120 mm were cast to perform the study. Considering the practical difficulties in the construction field in obtaining river sand, industrial sand was used for making the specimens eco-friendly. On completion of the prescribed curing period of 28 days, the cube specimens were subjected to a compression test to ensure the grade of the mix design, and the column specimens were subjected to axial loading and were tested in two categories, with and without wrapping of GFRP sheets' split tensile strength. Compression tests on cubes and columns were done. The nondestructive test was also performed with the ultrasonic pulse velocity (UPV) method to check the dense nature of the concrete before and after wrapping with GFRP. On comparing the results, it was observed that it is possible to obtain a higher strength using industrial sand when supported with suitable admixtures and strengthening processes.

1. Introduction

The use of natural resources in concrete is unavoidable in concrete mix, and it is a combination of cement, fine aggregate, mainly river sand, and coarse aggregate. However, the uncontrolled population growth has led to rapid urbanization, which indeed has led to the depletion of natural resources and an increase in the disposal of industrial, agricultural, and construction wastes [1]. Present work aims at developing suitable concrete with other sources from industrial waste so that the natural resources can be preserved to some extent. In this regard, the use of two industrial wastes, one for cementitious material and another for river sand, was followed in this research to develop high-strength concrete. Furthermore, to check the practical application, column elements were made with the obtained mixes and the behavior of the structural elements was studied, in addition to which the techniques for repairing the concrete columns made with such industrial wastes were also discussed.

1.1. Use of Industrial Waste in Construction. Researchers have already reported the use of such wastes in construction as a partial replacement for cement or in the form of fine aggregates. Fly ash, silica fume, ground granulated blast furnace slag (GGBS), and waste glass are some of the industrial wastes that are frequently preferred by researchers to be used in concrete as a partial replacement for cement [2–6]. In the present research, GGBS was used as a partial replacement for cement, GGBS is an industrial by-product obtained during the manufacture of pig iron as a chemical. As the chemical composition of GGBS resembles that of cement, it was chosen as a partial replacement for cement in the present work. Since sand occupies a larger quantity than cement in concrete and also as it plays a major role in making the concrete a solid one by reducing volume changes and filling up the pores or voids in the concrete, its demand is also very high. This demand for sand, if not controlled, will result in the nonavailability of good quality sand. To avoid such a situation, it is a good practice to use artificial sand for the construction process. In the construction field, agricultural wastes such as rice-husk ash, sugar cane bagasse ash, oyster nutshell, and sawdust were some of the few known wastes that were being used as a partial replacement for river sand [7–11]. Sivakumar et al, [12] have used Garnet and Al-fly ash in their work and other industrial wastes such as copper slag, steel slag, and iron ore tailings have also been utilized as a partial substitute for fine aggregates [13–16].

In this paper, the use of industrial sand as a full replacement for natural river sand has been discussed. Industrial sand is obtained by crushing stone or rock particles into finer particles, and these particles contain mostly rock dust rather than silt and clay [17]. Researchers have already experimented with M-sand for various types of concrete and have stated that good quality concrete can be achieved by using industrial sand with high micro fine particles [18, 19]. Guan et al., [20] tested the bond behavior of concrete-filled tubular columns made with M-Sand and mentioned in their results that a higher bond strength existed between specimens made with M-Sand. In the current research, experimental investigations were conducted using 100% artificial sand for casting structural columns, and the observations were reported.

1.2. Repair and Rehabilitation: Necessity and Techniques Adopted. Reinforced concrete structures, though made with river sand and other conventional natural materials, face several engineering problems such as dampness, formation of cracks, corrosion of rebars, and also insufficient bearing capacity [21], and the repairing and strengthening of such structures has gained lot of attraction in recent decades. It becomes essential to study the effects of the structure when alternate resources and the techniques to strengthen them are used. Fiber reinforced polymers (FRP) are widely preferred for retrofitting.

Confinement of structural elements using fiber reinforced polymer (FRP) is a commonly adopted technique and many studies have reported on using FRP to strengthen conventional concrete. Researchers have reported that wrapping of columns with FRP is one of the most effective applications [22–25]. Experimental investigations by earlier researchers report that FRPs are preferred due to their lightweight, low thermal conductivity, resistance to corrosion, great mechanical properties, and high ductility compared with reinforced columns [22, 26–28]. Glass fiber reinforced polymer (GFRP) and carbon fiber reinforced polymer (CFRP) are the most commonly used forms of FRP for retrofitting. Hadi et al. [29] have discussed the effects of using CFRP in hollow-core concrete columns and reported that CFRP confinement improved the ductility of the column than the strength. The use of CFRP has extended to ultra-high-performance concrete (UHPC) too. Lam et al. [30] presented the experimental investigations of UHPC columns confined by FRP. Researchers have reported many works related to GFRP. Kumudha et al. [31] presented the experimental investigations on rectangular concrete columns confined with GFRP wrapping and stated that better improvement in compressive strength was achieved when the numbers of GFRP layers were increased. Rahul and Urmil in 2013 [32] reported the experimental results of GFRP wrapped columns in different sections, namely, circular and rectangular sections. Rodsin [33] investigated the confinement effects of using a low-cost GFRP in columns made with clay bricks as coarse aggregates. The authors reported that circular columns had undergone more axial deformation than other sections, and it was controlled effectively by GFRP confinement.

1.3. Research Significance. The novelty of the current research is to estimate the damage assessment on structural elements made with industrial waste and artificial sand and to discuss the techniques to repair the damaged structural elements. Even though many focused research works are available for strengthening of circular columns, relatively less work has been performed on columns with industrial or artificial sand as fine aggregate used 100% as a replacement for natural river sand. Due to the depletion of natural resources and also the urbanization process, the scarcity of natural sand will become a major problem in the future, and it is time to try other alternatives. This paper tries to fulfil this endeavor.

Considering the literature details mentioned above, this paper discusses the following:

(1) Strength of cube specimens cast with cement partially replaced with GGBS in 0%, 15%, 25%, 35%, and industrial sand used fully as a replacement for river sand

(2) Axial strength of column specimens cast with the abovementioned combination

(3) Axial strength of damaged columns after retrofitted with GFRP layers

(4) Axial strength of GFRP columns directly without subjecting them to any damage before comparison

2. Materials Used

2.1. Cementitious Materials and Aggregates. Ordinary Portland Cement (OPC) of 43-grade cement conforming to IS 8112 [34] was used. The specific gravity of cement is 3.15.

In this study, artificial sand was used as a fine aggregate. Artificial sand, also known as industrial sand or M-sand, is manufactured by crushing large stones, boulders, and fewer grains of sand. The fineness modulus and specific gravity of sand are 3.8 and 2.63, respectively, which are consistent with

Zone II as per IS 383-1970 [35]. The advantages of M-sand are its high-compressive strength. It has fewer impurities, which results in a better quality of concrete. The artificial sand used in the present research is shown in Figure 1. The gradation curve of the artificial sand obtained from sieve analysis is shown in Figure 2. Though it is slightly coarser than river sand, the particles are distributed and proper packing can be ensured if the material is used in the concrete.

A crushed coarse aggregate of 16 to 20 mm in size was used. The modulus of the degree of fineness and the specific gravity is 3.8 and 2.63, respectively, which is consistent with Zone II as per IS 383-1970.

Ground granulated blast slag furnace (GGBS) shown in Figure 3 was used as a partial replacement of cement at different percentages. The specific gravity of GGBS is 2.85 to 2.95 as received from the manufacturer, and the size was analyzed using a zeta analyzer and is found to be 0.1 to 0.6 micron which is presented in Figure 4. To check the nature of the GGBS used, XRD analysis was performed from which it was noted that the material is not fully crystalline and it possesses amorphous nature. Figure 5 shows the XRD pattern of the GGBFS used.

Superplasticizer- CONPLAST SP 430 was used to achieve a workable concrete mix.

2.2. GFRP Sheets. Glass fiber reinforced polymer is used as a retrofitting material and also for strengthening purposes in this investigation. It is a unidirectional glass fiber with a size of 1.37 × 45.72 m roll. The elastic modulus of the sheet is 72.4 GPa and its tensile strength is 3240 MPa. These values are as per manufacturer specifications. Figure 6 shows the sample GFRP sheet used in the current research.

2.3. Mix Proportion. A nominal concrete mix possessing a compressive strength of 30 MPa was designed as per IS 10262- 2019 [36] and the mix proportion arrived was 1 : 1.7 : 2.5. A total of 4 mixes, including one control (C) mix, were made. C, GG15, GG25, and GG35 represent the mixes in which GGBFS was replaced for cement in 0, 15, 25, and 30 percentages. Cubes of size 100 mm × 100 mm × 100 mm were cast to check the compressive strength of the mix. Mix proportion details are listed in Table 1.

2.4. Casting and Repairing of Column. The same mix proportions were used for preparing the column specimens too with and without wrapping. Reinforced concrete columns of size 600 × 120 mm were made with 4 numbers of 8 mm longitudinal bars and 6 mm stirrups. For each mix proportion, two categories, namely, with and without wrapping of GFRP, were made, thus making a total of 7 combinations including control. Figures 7 and 8 show the reinforcements used and the columns after casting.

2.5. Rehabilitation of Column. The rehabilitation process was proceeded with the jacketing process using GFRP wrap. The surface of the concrete column was prepared by grinding the rough surface, followed by removing all the sharp corners. Epoxy resin was coated on the surface of the columns, and

Figure 1: M-sand.

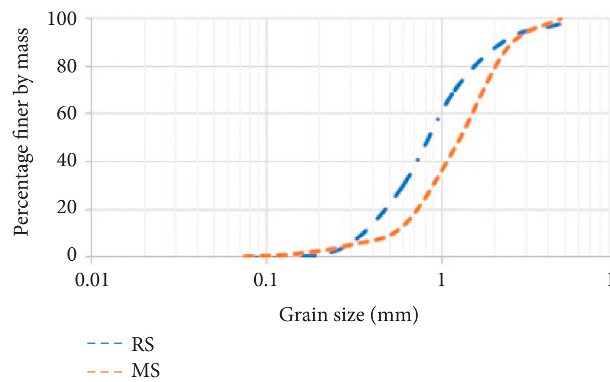

Figure 2: Particle size distribution of river sand and M-sand.

Figure 3: GGBS.

the specimens were left to stick to the surface. Thermax max-treat epoxy resin is prepared by mixing 125 g of max-treat saturant hardener with 1 kg of max-treat saturant resin. The GFRP sheet was then wrapped around the column with 2 layers and was pressed well. Epoxy resin was applied again to the GFRP wrap and the specimens were left to dry.

3. Testing Methods

3.1. Compression Test. Specimens of size 100 × 100 × 100 mm were cast and tested till failure. Preliminary testing on cubes

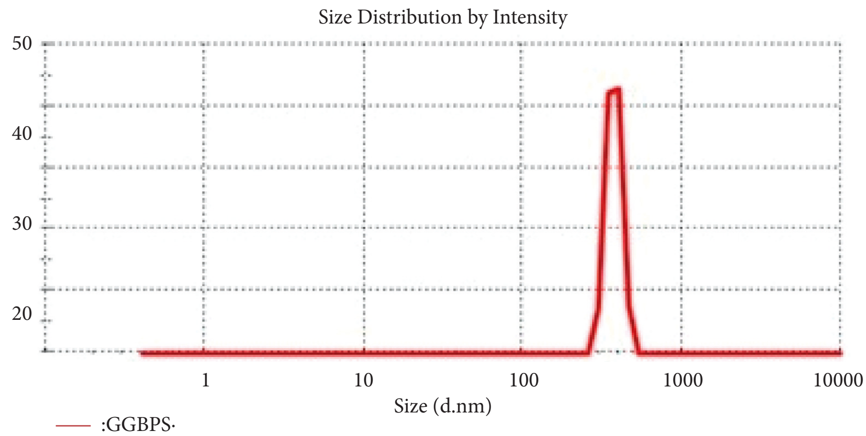

Figure 4: Size analysis using zeta analyzer.

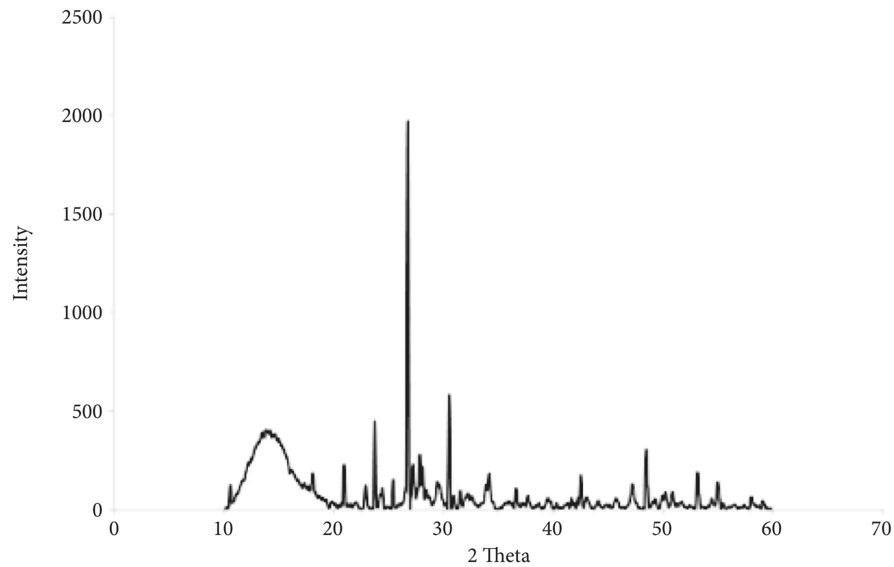

Figure 5: XRD pattern for GGBS.

Figure 6: GFRP sheets.

Table 1: Mix proportion.

Mix ID	C	GG15	GG25	GG35
GGBS, replacement percentage	—	15	25	35
Fine aggregate (industrial sand), kg/m^3		544.18		
Coarse aggregate, kg/m^3		1113.84		
Superplasticizer		1.5 *l* per 100 kg of cement		
w/c		0.36		
Mix ratio		1 : 1.04 : 1.3		

for compressive strength has been carried out. The test was done as per IS 516-1959 [37] till failure using a compression testing machine (CTM) of 3000 kN capacity.

3.2. Ultrasonic Pulse Velocity (UPV). The ultrasonic pulse velocity (UPV) test is a nondestructive test to check the quality of concrete. In this test, ultrasonic pulses are used to check the quality of concrete and also to ensure that the concrete is denser. The depth and width of the cracks, if any, in the pores in the concrete can also be detected from this test, and the strength was assessed by measurement of the velocity of an ultrasonic pulse passing through the concrete column. Ultrasonic pulse velocity test as per IS:13311(Part 1), 1992 [38], has been carried out to compare the crack velocity in the column before repairing and after the process of rehabilitation. The details of the test being conducted are illustrated in Figure 9.

Figure 7: Reinforcements used in column casting.

Figure 8: Columns' specimens.

3.3. Axial Loading in UTM. A 1000T column testing machine was used for performing the axial load testing. An axial load is applied along the longitudinal or centroidal axis of a structural member such that it produces no moment. The crack and ultimate load failure due to axial loading were noted. The test setup shown in Figures 10 and 11 shows the damaged column after testing. Figure 12 shows the specimens wrapped with GFRP.

4. Results and Discussion

4.1. Compressive Strength. Figure 13 illustrates the comparison of the compressive strength results of all mixes with control concrete. The compressive strength increased with an increase in replacement levels of GGBS. However, since no significant variation in strength was found after 25% replacement, replacement levels up to 35% were considered.

Figure 9: UPV test being conducted on column specimens.

Figure 10: Test set up for axial loading.

GG35 has shown the highest compressive strength among all combinations, and C has registered the least strength. Except for C, all specimens have shown strength either equal to or

Figure 11: Column after being subjected to damage.

Figure 12: Column specimens wrapped with GFRP.

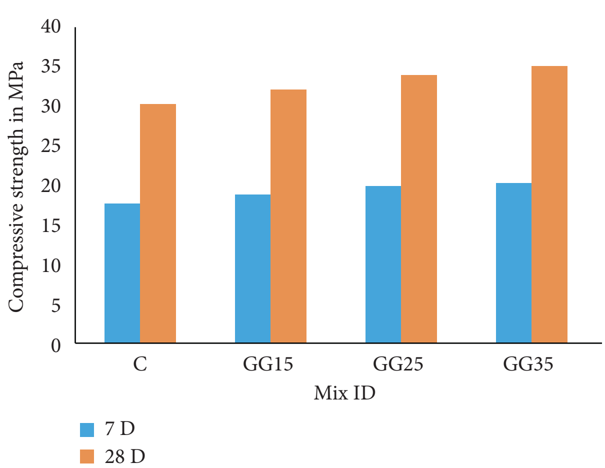

Figure 13: Compressive strength test.

more than the mean target strength required for M30. Though the mean target strength for M30 grade should be more than 30 MPa, the values obtained for the mix are closer to 30 MPa or slightly more because this project aims to use industrial sand and the results obtained on using it were found to be slightly less. Since it was decided to study the axial load carrying capacity of columns with 100% replacement of industrial sand for river sand, the same was tried with the cubes to check the possible strength, and the mix showed a promising strength equivalent to that of an M30 grade.

4.2. Axial Load Resistance of Unwrapped Columns. Figures 14–Figure 17 show the load vs. deflection details of the unwrapped columns for different combinations of GGBS. Control specimens possessed the lowest axial load resistance. All the specimens with GGBS have possessed a reasonable increase in axial strength. GG35 specimen, which possessed better compressive characteristics, has shown better performance in axial strength resistance too and has shown a peak resisting value of 375.6 kN which is 10.76% more than the load resisting characteristics of the control specimens.

4.3. Axial Load Resistance of Columns Repaired with Wrapping. The load-deflection details of the column specimens which were tested without wrapping and later tested once again after rehabilitating them with two layers of GFRP specimens are illustrated in Figures 14 to 17. Also, it is observed from the results that there is a significant improvement in the load resistance in the column specimens after wrapping. Even without wrapping, the columns showed a considerable increase in the axial loads with the increase in the replacement levels of GGBS; after being repaired with GGBS sheets, their load resisting capability increased by 23.7%, 42.2%, 59.6%, and 66.27% for control, GG15, GG25, and GG35 specimens. It is understood that the inner core of the concrete has not been damaged much, and the mix along with GGBS and industrial sand has put up a better resistance against the axial load. The pozzolanic action of GGBS, proper bonding of the mix with the aggregates, and better wrapping techniques have led to the high load resisting capability for the specimens.

4.4. Axial Compression Test on Columns after Strengthening with GFRP. Strengthening of the column is a process to restore or add the ultimate load-bearing capacity of the column. Though strengthening of the column is a process of adding or restoring the ultimate load capacity of a damaged reinforced concrete column, the GFRP wrap column strengthening technique has been adopted in present work on normal columns before they are subjected to any load conditions to observe the variations in the load carrying capacities of a normal column without wrapping and after strengthening with GFRP. The reinforced concrete column in each mix has been strengthened and tested for ultimate load failure by giving axial load to the column. The axial load carrying capacity has increased as the percentage of partial replacement of GGBS increases with GFRP wrap. The damaged columns, after being retrofitted with GFRP wrapping and with partial replacement of GGBS, have shown a drastic improvement in load carrying capacity. The

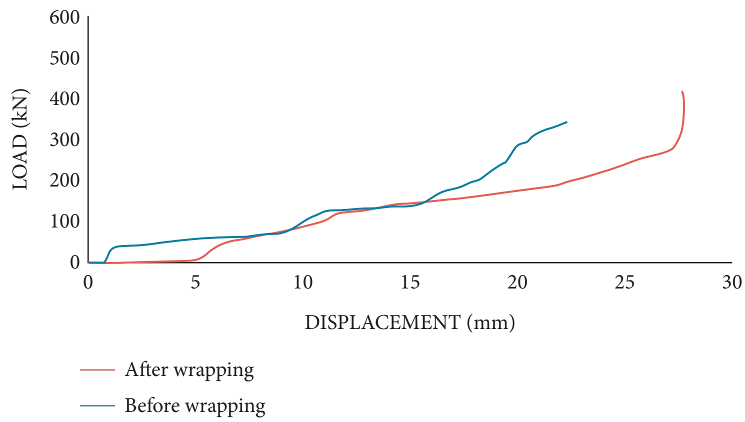

Figure 14: Load-deflection behavior of C specimens before and after wrapping.

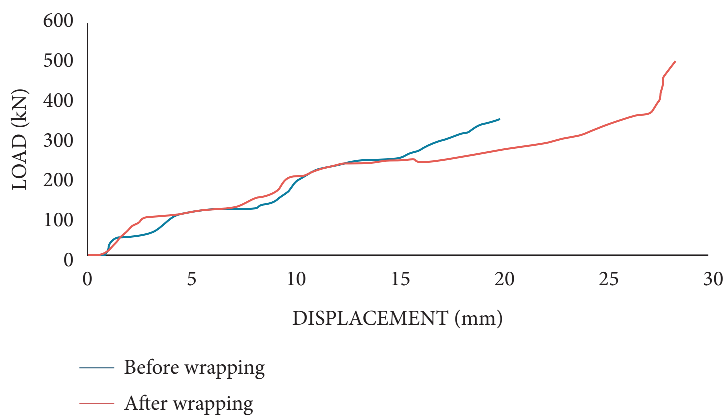

Figure 15: Load-deflection behavior of GG15 specimens before and after wrapping.

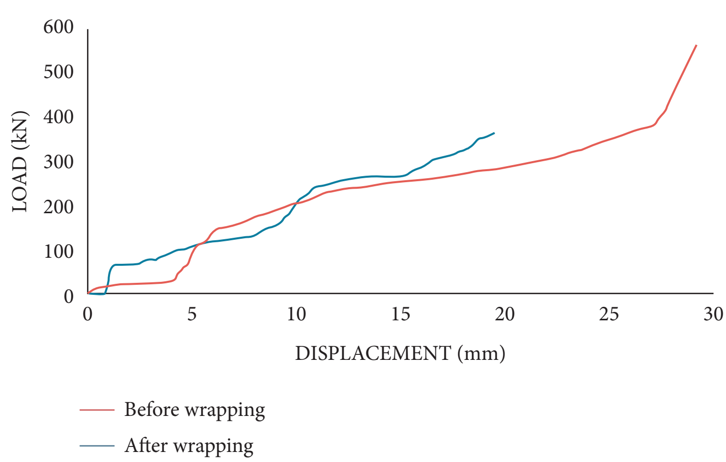

Figure 16: Load-deflection behavior of GG25 specimens before and after wrapping.

peak load carrying capacities of the columns have increased to 625.1 kN for GG35 specimens which is the maximum among all and is 66.42% more than the peak load carrying capacity of the specimen without any wrapping. Other specimens have also shown considerable improvement in load carrying capacity. The results are illustrated in Figures 18 to 21.

4.5. Ultrasonic Pulse Velocity Test. Table 2 shows the ultrasonic pulse velocity values of column specimens tested with wrapping and without wrapping. It is observed that the UPV values increase with the increase in the replacement levels of GGBS. Earlier researchers have also confirmed that use of supplementary materials will help improving the UPV values as the microcracks developed are properly filled by

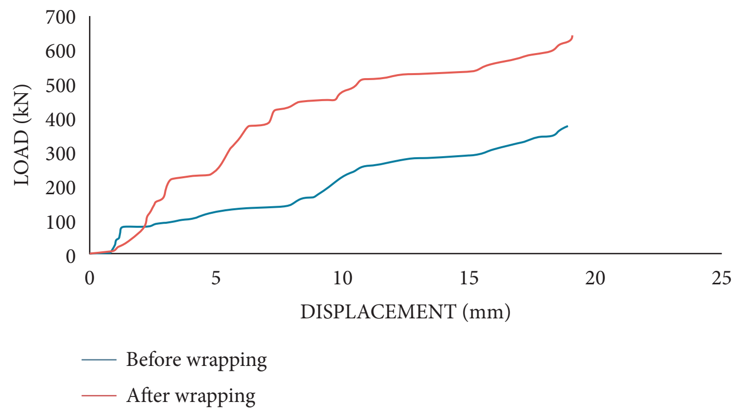

Figure 17: Load-deflection behavior of GG35 specimens before and after wrapping.

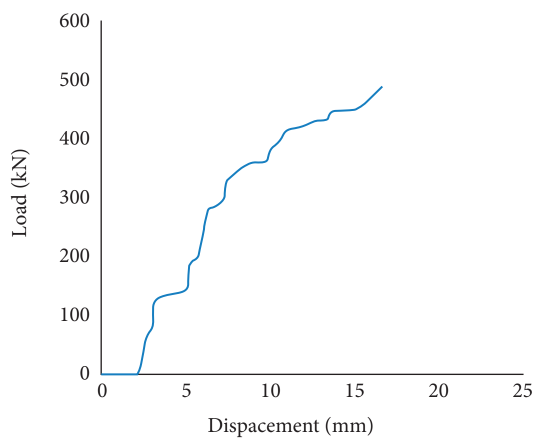

Figure 18: Load-deflection behavior of C specimens strengthened with wrapping.

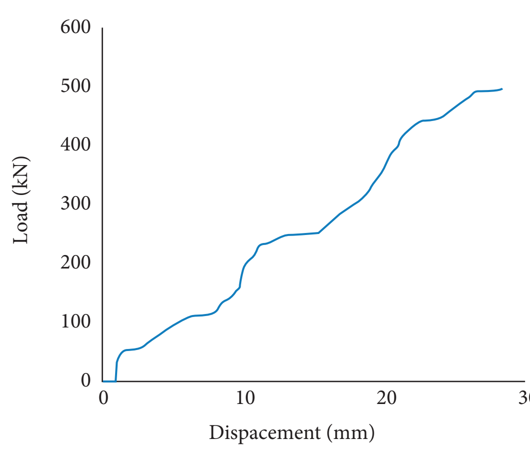

Figure 19: Load-deflection behavior of GG15 specimens strengthened with wrapping.

them. Yang et al. [9] reported the compressive strength results of concrete with oyster shells as fine aggregate and reported that the concrete showed an increase in compressive strength by 5% without admixture and suggested that it can be improved to 10% with proper admixture usage in concrete. They mentioned regarding the UPV values that it was higher for 5% replacement and stated that the lower UPV values were due to the weakness of the C-S-H gel. Iam and Makul [10] in their research stated that the UPV values usually increased when the concrete is made with supplementary cementitious mineral admixtures as the micropores in the concrete structures get filled due to the pozzolanic effect. They also mentioned that better relation existed between the compressive strength of concrete and UPV of self-

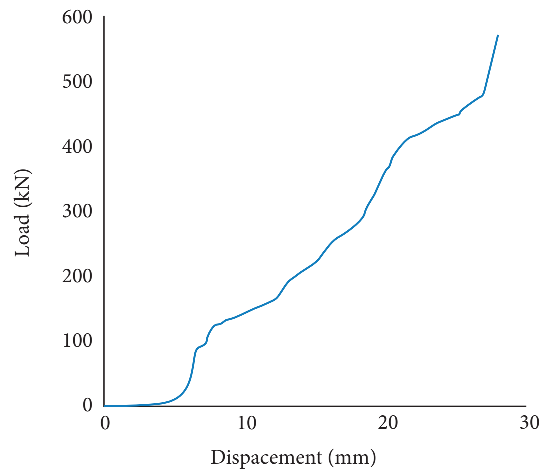

Figure 20: Load-deflection behavior of GG25 specimens strengthened with wrapping.

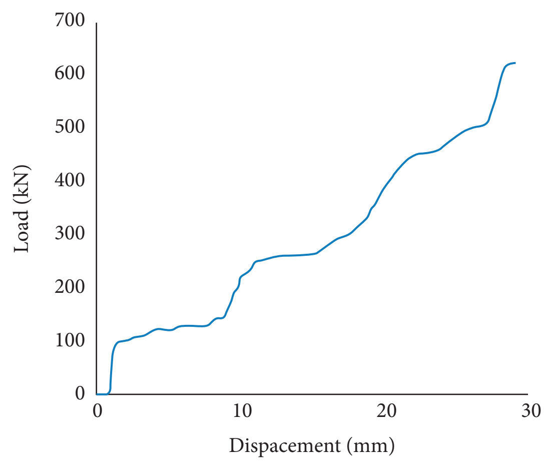

Figure 21: Load-deflection behavior of GG35 specimens strengthened with wrapping.

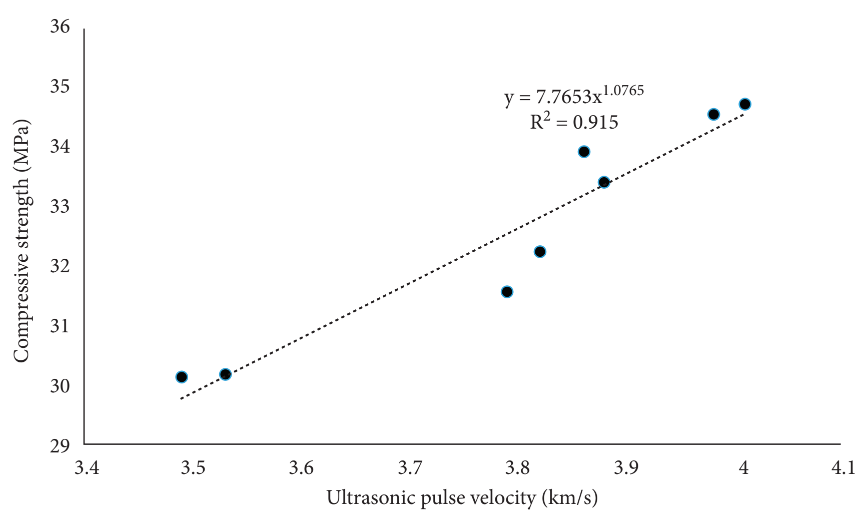

Figure 22: Comparison between compressive strength and UPV values.

compacting concrete made with rice husk. The same works well here too that the UPV values are higher for GG35% which possessed the highest compressive strength in cubes. The relation between the compressive strength and ultrasonic pulse velocity of the unwrapped column specimens is presented in Figure 22. A regression analysis has been

Table 2: Ultrasonic pulse velocity test results.

Sample ID	1st crack occurrence velocity (km/s)	
	Before wrapping	After wrapping
C	3.53	4.12
C	3.49	4.08
GG15	3.79	4.26
GG15	3.82	4.35
GG25	3.88	4.56
GG25	3.86	4.48
GG35	3.98	4.51
GG35	4.01	4.63

performed and from which a relation between the compressive strength of concrete made with industrial sand and GGBS and the ultrasonic pulse velocity can be derived.

5. Conclusions

The following conclusions were derived from the experiments:

(i) All the specimens cast with the industrial sand have achieved a strength closer to the mean target strength required for M30 concrete

(ii) The partial replacement of cement with GGBS has gradually increased the compressive strength up to 35%

(iii) The axial load resisting capacity of the columns with industrial sand as fine aggregate increased with an increase in the replacement level of GGBS

(iv) A massive improvement was observed in the load resisting behavior of the columns after they are retrofitted with GFRP wrapping

(v) Finally, the combined action of the pozzolanic reaction by GGBS and the effective wrapping by GFRP provided adequate strength to the concrete to overcome structural failures

6. Future Scope

This report presents the discussion on the macrostudies or the mechanical strength details of concrete columns made with industrial waste and artificial sand. The strength of cube specimens was nearer to the design strength of 30 MPa and not very much greater than that. One of the reasons may be due to the large replacement of 35% cement with an industrial waste such as GGBS and another reason may be due to the utilization of industrial waste fully for the work. The study can further be expanded by performing microstructure analysis after analyzing the samples from the low- and high-strength cubes and by suitably modifying the mixed proportions of cement and GGBS. Further improvement can also be made by utilizing river sand along with the industrial sand instead of using industrial sand fully for the research.

Data Availability

All data are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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