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Strength and permeability of ferrocement structure by using ground granulated blast furnace slag

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Abstract
A reinforced mortar type that can be created with a relatively thin thickness is ferrocement. Using ferrocement as a mechanically sound and sustainable building material has produced several benefits, including less use of raw materials, decreased accumulation of waste materials, and reduced greenhouse gas emissions. Cement as a constituent material of ferrocement is an environmentally unfriendly material; therefore, a more environmentally friendly cement replacement material is needed, namely Ground Granulated Blast Furnace Slag (GGBFS). Thus, creating sustainable (green) fertilizers is the main goal of this work. There are three primary stages to experimental work: Using slag cement (GGBFS) in place of partial cement of 0%, 10%, 20%, and 30% is the initial step. The primary reinforcement in the second level is wire-welded mesh, with volume fractions of support (Vf) of 1.2%, 1.8%, and 2.4%. During the final phase, a maximum of three different test objects were tested for compressive strength, water penetration depth, and flexure at a 28-day age. According to the findings, employing GGBFS led to good mortar performance. According to studies on mortar, the percentage of GGBFS utilized in a work may be determined by comparing the GGBFS substitution rates of 10%, 20%, and 30%, which show no differences in tendency. The test findings did not considerably improve the bending strength and cracking behavior of ferrocement reinforced with wire-welded mesh. One of them is influenced by the age of the concrete; at 28 days, the added material GGBFS has not yet reached its maximum strength, which results in a negligible improvement in bending strength and cracking behavior.

Keywords:
Compressive Strength;
Concrete Material;
Ground Granulated Blast Furnace Slag;
Permeability;
Water Depth Penetration;

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INTRODUCTION

Ferrocement is a special form of reinforced concrete construction with an actual composite action between the cement matrix and the mesh. Ferrocement is a thin reinforced concrete formed from hydraulic cement mortar with several layers of wire mesh as the primary reinforcement with a relatively small wire diameter. Ferrocement can be reinforced with mesh made of metal or other materials. The reinforcement's uniform distribution and high surface area to volume ratio result in a better crack arrest mechanism. The volume fraction of reinforcement is essential in the ultimate strength-bearing capacity. Ferrocement raw materials are readily available and can be processed in any form. Ferrocement can be formed into panels or thin sections; most ferrocement is between 3 cm and 5 cm thick with only a slim mortar cover over the outermost reinforcement layer.

The advantages of ferrocement include ease, cheapness, strength, flexibility, lightness, and simplicity. Ferrocement is a simple technology that is easy to apply and replicate, has lower construction costs than other conventional materials, and is easily adapted to physical, mechanical, and hydraulic principles. Ferrocement is known to have good strength, flexibility, and durability. Ferrocement can be made in-situ or molded elsewhere and assembled in the field. Ferrocement reinforcement can be built into the desired final shape, and mortar can be plastered on-site without molds.

The extensive use of natural resources has released large amounts of carbon dioxide (CO_2) gas into the atmosphere, as well as the accumulation of waste materials resulting from industrial processes and the daily use of artificial materials, which are common reasons for environmental degradation. One example is the cement industry. The cement industry is considered one industry that contributes to greenhouse gas emissions. Using concrete with Portland cement as the main ingredient releases carbon dioxide (CO_2), contributing to greenhouse gas emissions in the atmosphere. The production of one ton of cement contributes to releasing one ton of CO_2 gas. In addition, it accounts for 7% of the world's CO_2 emissions. CO2 is generated from the calcination process of limestone, fuel combustion in kilns, and power generation. The total estimated carbon emissions from cement production in 1994 were 307 million metric tons of carbon (MtC), 160 MtC from process carbon emissions, and 147 MtC from energy use. Overall, the ten largest cement-producing countries in 1994 accounted for 63% of global carbon emissions from cement production. The average intensity of carbon dioxide emissions from total global cement production was 222 kg C/t cement. Emission mitigation options include improved energy efficiency, new processes, switching to low-carbon fuels, use of waste fuels, increased use of additives in cement manufacture, and, ultimately, alternative cement and removal of CO2 from flue gases in clinker kilns. Therefore, reducing the use of cement by using some waste materials as supplementary cementitious materials (such as slag cement (GGBFS)) in concrete production can contribute to solving some environmental problems and positively impact the cement matrix's economic side and mechanical properties.

Ground Granulated Blast-Furnace Slag (GGBFS) is obtained by cooling molten iron slag (a by-product of iron and steel making) from blast furnaces in water or steam to produce a glassy granular product that is then dried and ground into a fine powder. GGBFS is now widely used in several countries to partially replace ordinary Portland cement or other pozzolanic materials due to its similar composition to cementitious materials. GGBFS cement is routinely applied in concrete and mortar materials. Some of the advantages of using GGBFS are higher ultimate strength compared to ordinary concrete using only Portland cement, reduced concrete pores due to finer particle size than regular cement, and improved appearance of the structure as its almost white color allows architects to get lighter colors for concrete finishes, and provides a more environmentally friendly material compared to Portland cement. In addition to slag cement, several researchers have also conducted research related to the utilization of slag products (steel slag), which have various advantages in the construction field [1, 2, 3].

Many studies have been conducted to understand the behavior of GGBFS materials in replacing ordinary Portland cement. Dewi et al. [4] investigated the characteristics of concrete paste with partial cement replacement with GGBFS. The results showed that increasing the replacement level of GGBFS at a specific limit led to higher workability of the concrete paste. Ganesh and Murthy [5] investigated GGBFS as supplementary cementitious materials (SCMs) for cement replacement. GGBFS was used in ultra-high-performance concrete (UHPC) up to 80% cement replacement level, and it was found that the hardened properties of GGBS-based UHPC are significant up to 40% cement replacement level under standard water curing. Elevated temperature curing improves its performance up to 60% replacement level. Ahmad et al. [6] investigated the characteristics of concrete using GGBFS as a binder in recycled aggregate fiber-reinforced concrete (RAFRC). A reduction in water absorption and dry shrinkage cracking was observed by substituting GGBFS into the RAFRC. Vediyappan et al. [7] stated that the optimal percentage of replacement of GGBFS with micronized biomass silica (MBS) concerning weight is 20%. While Raafidiani et al. [8] said that 50% GGBFS substitution can partially replace cement because it has the same compressive strength as regular concrete and is environmentally friendly.

Many studies have discussed concrete strength. Majhi et al. [9] investigated the effect of recycled coarse aggregate (RCA) and GGBFS on fresh and hardened concrete properties and found that the use of GGBFS improved the quality of concrete mixes by increasing the interface transition zone (ITZ) and bond between mortar and RCA. Lenka et al. [10] investigated the effect of replacing cement with GGBFS, fine aggregate with GBFS, and coarse aggregate with recycled coarse aggregate (RCA) on concrete's fresh mortar properties, mechanical properties, and durability. As a result, the tensile, flexural, and split bond strengths showed satisfactory performance, and the durability against sulfuric acid and chloride ion ingress was comparable or better. Prakash et al. [11] investigated the mechanical properties and durability of ultra-high performance concrete (UHPC) containing Silica Fume (SF) and GGBS. Based on the findings, the strength properties of GGBS-based UHPC are significant up to a cement replacement level of 40%. Suda et al. [12] investigated that GGBFS has a positive effect on the workability of ternary systems and retards early age strength. Research related to strength properties through compressive strength tests and durability properties through water penetration tests under pressure was also investigated by Kalaimani and Srinivasan [13].

This research uses ferrocement as the structure to be tested along with GGBFS, which serves as a substitute for cement. In ferrocement, the fineness of the mortar matrix and its composition must match the mesh and skeletal system to be encapsulated. So, the use of GGBFS in ferrocement needs to be examined, considering that the fineness of GGBFS material is smaller than that of cement. The reinforcement's uniform distribution and high superficial area-to-volume ratio result in a better crack arrest mechanism. In addition, the volume fraction of reinforcement plays a vital role in the highest strength-bearing capacity of ferrocement. Various studies have been conducted on ferrocement with various reinforcements such as Carbon Fiber Reinforced Polymer (CRFP)[14], steel fiber [15], basal fiber [16], Natural Sisal Fibre (NSF) [17].

Jayaprakash et al. [18] investigated ferrocement with steel slag as a fine aggregate replacement. The 30% GGBFS substitution and 3.77% reinforcement volume fraction in ferrocement showed better performance in load-deflection behavior, first crack load, ultimate load, energy absorption, and ductility ratio than other specimens. Jaraullah et al. [19] investigated the properties of mortar containing GGBFS and Metakaolin (MK) on ferrocement. The utilization of GGBFS and MK provided good mortar performance. GGBFS and MK can reduce the adverse effects on workability, improve mechanical quality, and increase the homogeneity of the mixture with a single substitution of MK or GGBFS. Vinoth, R [20] investigated ferrocement as a coating on reinforced concrete beams. The results show that tightly spaced ferrocement provides flexural strength and minimizes the crack width between beam specimens. Domenico et al. [21] investigated using electric arc-fired (EAF) slag as a partial or complete replacement for fine aggregate. It was found that the presence of steel slag resulted in higher flexural and shear capacities, reduced crack width, and increased ductility. Rashid et al. [22] stated that the double-layer mesh specimens in ferrocement showed better results in strength and corrosion parameters when compared to the single-layer mesh specimens. Finally, the primary objective of this study was to investigate the effect of GGBFS as a cement replacement material in ferrocement with several variations of reinforcement volume fraction.

Ferrocement is directly related to water, such as its utilization for irrigation networks, shell structures, coastal/jet structures, and many more. This research is vital because GGBFS is a material derived from waste utilization and functions as an adhesive that can replace part of the cement material to reduce the use of cement. In addition, the fineness of GGBFS powder, which is smaller than cement, and its adhesion have many benefits for ferrocement structures, including water tightness and mortar strength.

METHOD

The research method used was experimental research conducted in the laboratory. The variables investigated included wire mesh reinforcement volume fractions of 1.20%, 1.80%, and 2.40% and GGBFS substitution levels of 0%, 10%, 20%, and 30%. The tests carried out include tests on the mortar, namely the compressive strength test and permeability test, and tests carried out on the ferrocement structure bending test. A total of 60 test specimens were made. Twelve cubes with dimensions of 5x5x5cm for the compressive test (Figure 1), 12 cubes with dimensions of 15x15x15cm for the water penetration depth test (Figure 2), and 36 ferrocement specimens with dimensions of 60x30x5cm for the flexural test (Figure 3). The mortar specimen codes are shown in Table 1, and the ferrocement specimen codes in Table 2. The tests were conducted after 28 days of mortar concrete age.

Table 1. Code of Mortar Specimen

Code of Specimens	GG BFS	Dimensions (cm)	S/C	W/C	No. Of Specimens
SC0A	0%	5x5x5	2.0	0.4	3
SC10A	10%	5x5x5	2.0	0.4	3
SC20A	20%	5x5x5	2.0	0.4	3
SC30A	30%	5x5x5	2.0	0.4	3
SC0B	0%	15x15x15	2.0	0.4	3
SC10B	10%	15x15x15	2.0	0.4	3
SC20B	20%	15x15x15	2.0	0.4	3
SC30B	30%	15x15x15	2.0	0.4	3
Total					24

Table 2. Code of Ferrocement Specimen

Code of Specimens	GGBFS	Vf	S/C	W/C	No. Of Specimens
SC0Vf1.2	0%	1.20%	2.0	0.4	3
SC0Vf1.8	0%	1.80%	2.0	0.4	3
SC0Vf2.4	0%	2.40%	2.0	0.4	3
SC10Vf1.2	10%	1.20%	2.0	0.4	3
SC10Vf1.8	10%	1.80%	2.0	0.4	3
SC10Vf2.4	10%	2.40%	2.0	0.4	3
SC20Vf1.2	20%	1.20%	2.0	0.4	3
SC20Vf1.8	20%	1.80%	2.0	0.4	3
SC20Vf2.4	20%	2.40%	2.0	0.4	3
SC30Vf1.2	30%	1.20%	2.0	0.4	3
SC30Vf1.8	30%	1.80%	2.0	0.4	3
SC30Vf2.4	30%	2.40%	2.0	0.4	3
Total					36

Figure 1. Cube Specimen with Dimension 5x5x5cm

Figure 2. Cube Specimen with Dimension 15x15x15cm

Figure 3. Ferrocement Specimen with Dimension 60x30x5cm

Material

The materials used to manufacture ferrocement are cement, fine aggregate, water, and wire mesh. As well as cement substitutes in the form of GGBFS. The sand used is a type of lumajang sand that has met the SNI ASTM C136-2012 standard, and the mud content is less than 3%. Water is clean with drinking requirements, according to SNI 7974: 2013 specifications. At the same time, the cement used is the Portland Composite Cement (PCC) Gresik Brand. The wire mesh used is Hot Dipped galvanized wire Mesh with a diameter of 1.1mm and a mesh spacing of ½ inch, XViper brand. The cement slag used as a cement replacement material is Ground Granulated Blast-Furnace Slag (GGBFS). GGBFS is in the form of fine granules from PT Krakatau Semen Indonesia (KSI) with the criteria in Table 3 and Table 4.

Research Procedures

The research was conducted in the laboratory to obtain data in the form of compressive strength data, water penetration depth data, Pcrack, and Pultimate. The research stages include material testing, making test specimens, treating test specimens, testing test specimens, and data processing (Figure 4).

The first stage is material testing, including the GGBFS powder activeness test and acceptable aggregate inspection. The GGBFS activeness test was carried out using the NI 20 - 1995 test method, i.e., GGBFS was mixed using slaked lime in the ratio of 1 Ls : 2 GGBFS.

Table 3. Chemical and Physical Content of GGBFS

Property	Unit	Result
Fe2O3	%	0.41
Al2O3	%	18.09
CaO	%	36.69
MgO	%	1.74
SiO2	%	37.86
LOI	%	0.01
Chloride	%	0.03
S	%	2.17
SO3	%	5.43
Glass Content	%	99.21
Alkalies (Na2O + 0.658 K2)	%	0.83
Fineness – Blaine	m2/kg	425
Moisture Content	%, AR	0.12
Retained on Mesh 325	%	2.25
Bulk Density Compact	g/cc	1.34

Table 4. Slag Activity Index in ASTM C898

Property		Unit	Result
Compressive Strength After	Seven days	MPa	21.65
	28 days		43.41
Slag Activity Index After	Seven days	%	75
	28 days		124

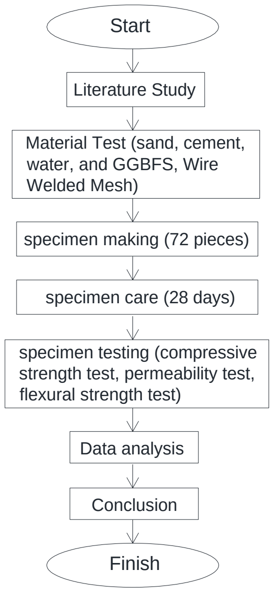


Figure 4. Research Flow Chart

The liveliness indicator can be done using a Vicat tool with a load of 800 grams. If within three days, the 1 mm diameter Vicat needle, after being dropped within 30 seconds, can enter the paste (a mixture of GGBFS + slaked lime) in a conical mold ≤ 2 mm deep, then the GGBFS powder is declared active. The examination of sand material includes specific gravity, organic matter content, grain content passing 0.075 mm sieve, content weight, gradation, moisture content, and mud content.

The second stage is the manufacture of test specimens by mixing materials such as sand, cement, water, and GGBFS with a mixer. The sand-cement ratio (s/c) by weight was 2.0, and the water-cement ratio (w/c) by weight was 0.4. Variations of GGBFS as a cement replacement were 0%, 10%, 20% and 30%. To obtain slump value data, the finished mortar mixture was tested for slump flow. Slump flow is one of the simple tests to determine the workability of fresh concrete before it is applied to the test mold. A new concrete slump must be done before concrete is poured to see indications of the plasticity of fresh concrete. If it has decreased enough, it can be decided whether new concrete is still suitable for use. The variation of reinforcement fraction in ferrocement (Vf) is 1.20%, 1.80%, and 2.40%. Two types of mortar test molds are 5x5x5cm and 15x15x15cm. One type of ferrocement mold is 60x30x5cm mold. After the test specimens were mixed, the mortar mixture was molded into the mold and allowed to stand in the mold for approximately 24 hours at room temperature for mortar and 72 hours for ferrocement test specimens.

The third stage is the treatment of test specimens carried out after the mortar test specimens are one day old, namely, the test specimens are removed from the mold and put into the water until they sink entirely. Immersion is carried out for 28 days at room temperature. Ferrocement test specimens were treated after they were three days old, the test specimens were removed from the mold, and wet gunny sacks covered the surface of the test specimens. After seven days, the gunny sacks were watered with clean water, and for the next seven days, for 28 days. After the test specimens were 28 days old, they were removed from the water and dried by wiping. Next, the test specimens were weighed to obtain the weight content data. Weight content is the ratio between the weight and volume of the model after the sample has hardened.

The fourth stage is testing the specimens. At this stage, the compressive strength, concrete permeability, and flexural tests were carried out. The compressive strength of concrete identifies the quality of a structure. The higher the strength of the desired design, the higher the quality of the concrete produced. Compressive strength is the ability of concrete to receive compressive force per unit area. The concrete compressive strength test is carried out with a compression test machine. The permeability of concrete can be interpreted as the ability of concrete to drain water through its pores. Permeability can be measured by determining the water flow rate through the object whose value is expressed as the permeability coefficient, k (cm/sec). The smaller the permeability coefficient of concrete, the higher the strength of the concrete. The coefficient of permeability of concrete states whether or not the concrete is easy for water to pass through. The higher the permeability coefficient, the easier it is for water to pass through the concrete. The permeability coefficient is calculated through the Darcy equation below:

$$k = \frac{dl}{dh} \cdot \frac{Q}{A.t} \qquad (1)$$

Where:

k = Permeability coefficient, cm/sec
Q = Total permeable water, (the amount of water collected in the measuring cup during time t), cm^3
A = cross-sectional area of the test specimen, cm^2
dh = P/(ρ.g), with P = 5 bar, ρ = 1 gr/cm^3, g = 980.665 cm/sec^2, cm
dl = penetration, cm
t = time required to achieve penetration, sec

The concrete permeability test used is the water penetration depth test. The penetration test is a substantial permeability test where no water flows to the sample, so only seepage occurs on the specimen. In DIN 1048 Part 5, the measured concrete permeability is the amount of water penetration into the concrete when pressurized water is inserted at 5 bars for approximately 72 hours. The specimen is split, and the depth of water penetration successfully passes through the model. The limit value of concrete permeability for watertight concrete is when water seeps into the concrete less than 5 cm.

Flexural tests were conducted on ferrocement containing wire mesh reinforcement and GGBFS. The ferrocement was supported by roller joint pedestals with a span of 500mm, and each pedestal was 50mm away from the edge of the slab. A pump pressurized a hydraulic jack mounted on a small frame system. The hydraulic jack presses the load cell, and the load in kN is read on the load indicator. The load is transmitted to the surface of the plate by a lateral load divider into a line load towards the width of the plate (three-point plate bending test). When the loading has been carried out, the plate flexes and compresses the LVDT installed at the center of the span, and the amount of deflection in mm will be read on the data logger.

RESULTS AND DISCUSSION

The result of the activeness test of GGBFS powder with the Vicat Tool is 1.0 mm with a maximum requirement of 2 mm so that GGBFS powder is declared active. The results of the examination of the fine aggregate found that the fine aggregate met the requirements of ASTM C 33. The results of the slump flow test on fresh mortar (Table 5) showed that the workability of new mortar with 10%, 20%, and 30% GGBFS substitution decreased when compared to that without GGBFS substitution. Each decrease was 35%, 42%, and 21% respectively.

The content weight of mortar dimension 5x5x5cm at 10%, 20%, and 30% GGBFS substitution increased by 2.10%, 4.26%, and 3.24% compared to without GGBFS substitution. The content weight of mortar dimensions 15x15x15cm increased by 0.89%, 3.46%, and 2.04% compared to no GGBFS substitution. Weight content data can be seen in Table 6.

Table 5. Slump Flow

GGBFS (%)	Slump Value (cm)
0	14.8
10	9.7
20	8.7
30	11.7

Table 6. Weight of Content

Code of Specimens	Weight of Contents (Kg/m^3)
SC0A	2221
SC10A	2268
SC20A	2316
SC30A	2293
SC0B	2226
SC10B	2246
SC20B	2303
SC30B	2272
SC0Vf1.2	2335
SC0Vf1.8	2327
SC0Vf2.4	2376
SC10Vf1.2	2323
SC10Vf1.8	2329
SC10Vf2.4	2353
SC20Vf1.2	2340
SC20Vf1.8	2377
SC20Vf2.4	2379
SC30Vf1.2	2323
SC30Vf1.8	2340
SC30Vf2.4	2408

The compressive strength of mortar with 10%, 20%, and 30% GGBFS substitution increased compared to that without GGBFS substitution (Table 7). The highest compressive strength value was in the mortar with 20% GGBFS substitution, which amounted to 37.80 MPa. The lowest compressive strength value was in mortar with 0% GGBFS substitution, which amounted to 31.87 MPa. The increase in compressive strength was 15%, 19%, and 18%, respectively (Figure 5).

The water penetration depth test results showed that GGBFS substitution decreased by 10%, 20%, and 30% compared to those without GGBFS substitution (Table 8). The lowest penetration depth value was 9 mm for the mortar with 30% GGBFS substitution and 22.33 mm for the mortar without GGBFS substitution. The decrease in penetration depth was 57%, 58%, and 60%, respectively (Figure 6). The permeability coefficient values calculated by (1) are shown in Table 9. The lowest permeability coefficient values are at the lowest penetration depth values and vice versa (Figure 7).

Table 7. Compressive strength

GGBFS (%)	Compressive Strength (MPa)
0	31.87
10	36.60
20	37.80
30	37.60

Table 8. Water Penetration Depth

GGBFS (%)	Water Penetration Depth (mm)
0	22.33
10	9.67
20	9.33
30	9.00

Table 9. Coefficient of Permeability

GGBFS (%)	Coefficient of Permeability (mm/sec)
0	2.52 x 10^{-7}
10	9.26 x 10^{-8}
20	7.44 x 10^{-8}
30	7.15 x 10^{-8}

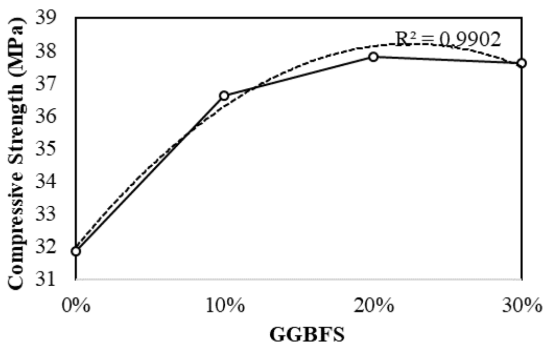


Figure 5. Graph of Relationship between GGBFS and Mortar Compressive Strength

Based on SK-SNI S-36-1990-03 [14], concrete is watertight if the penetration value that occurs into the concrete is a maximum of 50 mm for medium-aggressive water and 40 mm for strong-aggressive water. Based on the test results, the concrete mortar has met the requirements of waterproof concrete, both assertively aggressive and mediumly aggressive, as shown in Table 10. According to ACI 301-729 (Revised 1975) (in Neville and Brooks [23]), the maximum permeability coefficient value is 1.5 x 10-11 m/sec, so the mortar with 0%, 10%, 20%, and 30% GGBFS substitution does not meet the requirements shown in Table 11.

The flexural tests conducted on the ferrocement yielded results in first crack load data and ultimate load data.

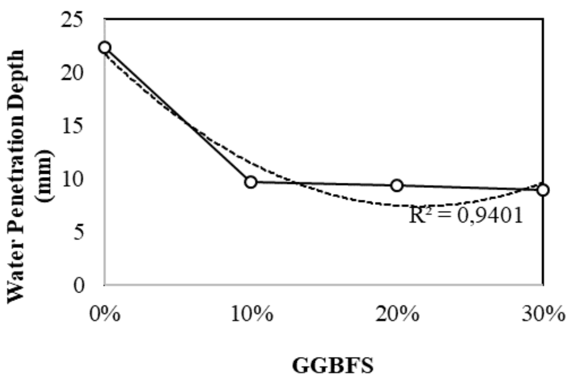


Figure 6. Relationship Graph of GGBFS with Penetration Depth of Mortar

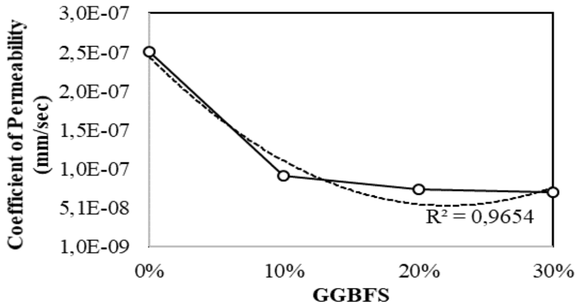


Figure 7. Graph of Relationship between GGBFS and Permeability Coefficient of Mortar

Table 10. Water Penetration Depth Terms

GGBFS Substitution (%)	Water Penetration Depth (mm)	SK SNI S-36-1990-03 Requirements	
		Strong Aggressive Terms (40 mm)	Medium Aggressive Terms (50 mm)
0	22.33	Eligible	Eligible
10	9.67	Eligible	Eligible
20	9.33	Eligible	Eligible
30	9.00	Eligible	Eligible

Table 11. Permeability Coefficient Terms

GGBFS Substitution (%)	Coefficient of Permeability (m/sec)	ACI 301-729 (Revised 1975) Requirements 1,5 x 10-11 m/sec
0	2.52 x 10^{-10}	Not Eligible
10	9.29 x 10^{-11}	Not Eligible
20	7.44 x 10^{-11}	Not Eligible
30	7.15 x 10^{-11}	Not Eligible

In Figure 8, for the SC20Vf1.2, SC201.8, and SC202.4 specimens, the first crack load was increased by 3%, 27%, and -9%, respectively, compared to SC0Vf1.2, SC0Vf1.8, and SC0Vf2.4. In Figure 9, for specimens SC30Vf1.2, SC30Vf1.8, and SC30Vf2.4 the ultimate load was increased by -16%, 14%, and 4% compared to SC0Vf1.2, SC0Vf1.8, and SC0Vf2.4, respectively.

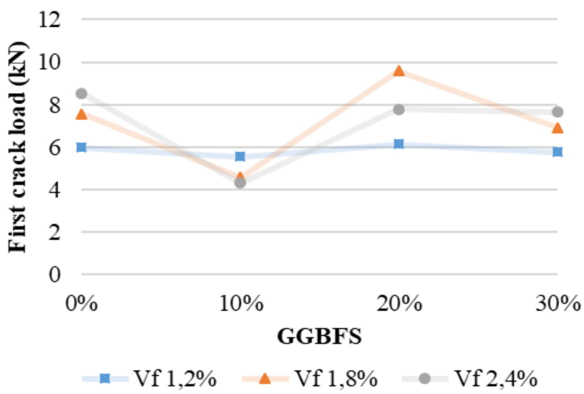


Figure 8. Relationship Graph of Pcr and GGBFS

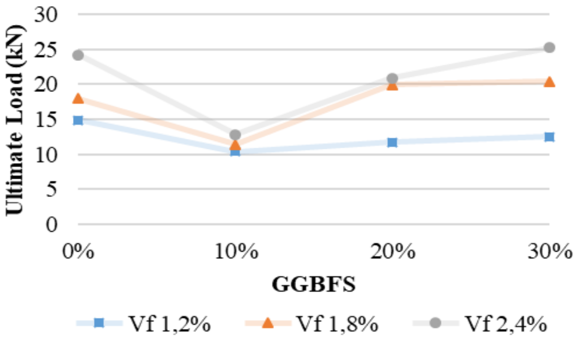
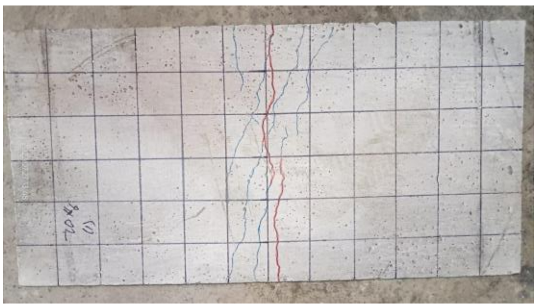
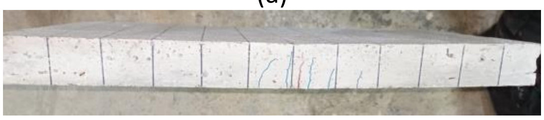


Figure 9. Pult and GGBFS Relationship Chart


(a)

(b)
Figure 10. Water Penetration Depth Test (a) and Readings (b)


(a)

(b)
Figure 11. Ferrocement After Testing

The effect of Ground Granulated Blast Furnace Slag as a partial replacement of cement by weight in this study can reduce the slump flow of fresh mortar. GGBFS has a finer particle size than cement, leading to an increase in surface area. In addition, partial replacement of cement with GGBFS results in lower paste volume due to its higher density, and this decrease in paste volume increases friction at the exemplary aggregate-paste interface, decreases cohesiveness and plasticity, and thus leads to reduced workability. This is supported by several studies that have been conducted that state that the use of GGBFS can reduce the workability of concrete [24][25].

Specimen cubes taken from a portion of the ferrocement mortar were tested for compressive strength using CTM by IS 516:1959. The average compressive strength tested at 28 days is tabulated in Table 7. Figure 5 illustrates the correlation between GGBFS content and compressive strength graphically. Figure 5 shows that the concrete mortar specimens with 20% GGBFS content obtained the maximum compressive strength. Similar to the research of Ganesh and Murthy [5], the compressive strength of models in standard curing with water for 28 days is at its maximum at 20% GGBFS substitution. The additional benefit of GGBFS in terms of strength is mainly due to the modification of the cement paste's microstructure, which can fill empty pores and reduce the pore volume of the matrix effectively. The graph of the GGBFS and compressive strength shown in Figure 5 shows that the relationship is not linear; the trends obtained with 10%-30% GGBFS substitution are similar or not different.

Permeability is significant in the manufacture of ferrocement structures. The permeability of concrete is determined by the water penetration depth method (Figure 10). Table 10 and Table 11 list the permeability test results. The relationship between permeability and utilization of GGBFS is shown in Figure 6 and Figure 7. From Figure 6 and Figure 7, it can be observed that specimens without GGBFS show the highest permeability and samples with GGBFS show the minimum permeability. The permeability of concrete is inversely proportional to its mechanical properties. The main reason for the decrease in permeability with increasing GGBFS content is that increasing GGBFS content reduces the void content of the concrete. In Figure 6 and Figure 7, the graphs of the relationship between permeability and GGBFS show nonlinearity. So, the greater the percentage of GGBFS substitution does not make the permeability decrease. However, a 10%-30% GGBFS percentage can inevitably reduce the permeability of concrete. The results in this study are from previous studies [6, 24, 26, 27]

The ferrocement specimens were subjected to flexural strength tests using UTM as specified in IS 516:1959. Figure 8 and Figure 9 display the graphs of the relationship between the first crack load and the ultimate load with GGBFS. Figure 8 shows that the highest first crack load is at 20% GGBFS and Vf 1.80%. Figure 9 shows that the highest ultimate bag is at 30% GGBFS and Vf 2.40%. This indicates that the effect of GGBFS as a partial replacement of cementitious materials based on cement weight can increase the structural strength of ferrocement during flexural tests.

The enhancement of flexural strength can be mainly contributed by the enriched bond between the paste and wire mesh in the binder phase of Ferrocement with GGBFS. The volume fraction of reinforcement can better improve the strength of ferrocement. The strength of ferrocement with GGBFS substitution in this study obtained results that did not significantly increase compared to without GGBFS substitution; this is in line with the statement stating that the increase in strength of concrete with GGBFS is at a higher maturity period (i.e., 56 days or more). The flexural strength results found that the failure was due to the lack of adhesion force within the matrix, not the aggregates' crushing. The strength may not be palpable at an early age due to the dilution effect of GGBFS in place of cement since the reactivity of GGBFS is very slow compared to Portland cement. This could be due to the low density of the C-S-H gel formed by the GGBFS particles in the hydration reaction or the unavailability of free calcium hydroxide for the pozzolanic response [5, 8, 9, 11, 12, 19, 26].

CONCLUSION

Based on the results, it was found that using GGBFS in mortar can provide good performance. Compressive strength increased, and permeability decreased due to GGBFS substitution. The highest compressive strength was at 20% GGBFS substitution, and the lowest permeability was at 30% GGBFS substitution. The results of research on mortar obtained a statement that the substitution of GGBFS 10%, 20%, and 30% has the same trend or is not different so that it can be used as a reference for the percentage of GGBFS use in a job. Test results on ferrocement reinforced with wire-welded mesh did not significantly improve flexural strength and cracking behavior. The highest first crack load was at 20% GGBFS and Vf 1.80%, while the highest ultimate load was at 30% GGBFS and Vf 2.40%. It happens due to the age factor of concrete, where at 28 days, the GGBFS added material had not reached its maximum strength, thus causing the flexural strength and cracking behavior not to increase significantly. However, GGBFS is recommended as a 10%-30% cement replacement material that can increase the strength of mortar, improve the water tightness of mortar, and save cement use.

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