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Original scientific paper

The Durability Behaviour of a Ferrocement Slab Utilizing Ground Granulated Blast Furnace Slag and Nano Silica

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Abstract: The fundamental purpose of this research is to evaluate the durability qualities of the geopolymer-based ferrocement slab element and analyze the ideal combination, as well as to determine if geopolymer mortar can be utilized in structural components instead of cement mortar and to improve properties. The compressive strength and durability properties of a Nano silica based geopolymer included ferrocement slab element experimentally studied in detail using Carbon Fibre Reinforced Polymer (CFRP) wound wire mesh at both room temperature curing and hot curing at 60 °C. Geopolymer is made here using fly ash. The geopolymer mortar for the cement slab is initially created using a 1:2 mortar ratio with the mix proposition of 65% fly ash, 25% sodium silicate, and 10% sodium hydroxide making up this binder. Ground Granulated Blast Furnace Slag (GGBS) was used to replace the weight of fly ash by 20%, 40%, 60%, 80%, and 100%. Although 100% GGBS in fly ash provided the best strength, the compressive test results indicate that 80% GGBS addition is optimal due to the early production of cracks. To improve performance, nano silica is added to the chosen combination in amounts of 0.5%, 1%, 1.5%, and 2% by weight of binder. Finally, superior combinations were established after testing the specimen's permeability, acid resistance, and heat resistance. The strength of the geopolymer mortar was improved by about 240% using 1.5% nano silica and 80% GGBS. The durability property of the geopolymer mortar was improved by about 90% using 1.5% nano silica and 60% GGBS.

Keywords: carbon fibre reinforced polymer (CFRP); durability; ferrocement; flyash; geopolymer; GGBS

1 INTRODUCTION

Numerous investigations in geopolymer technology have been conducted in an effort to perfect geopolymer concrete as the finest sustainable structural component. In this respect, employing Fly ash or Ground Granulated Blast Furnace Slag (GGBS) during the creation of the geopolymer binder might minimise CO_2 output. Fly ash geopolymers have been made into concrete, mortar, and paste forms. The IFA addition, gel formation was slowed, resulting in a loss in compression performance of the alkali activated GGBS-IFA binding material. On 60% substitution of GGBS by IFA, a moderate compressive strength of 17 MPa was produced; similarly, it efficiently restrains heavy metals [1]. Optimal mix proportion of ground granulated blast furnace slag (GGBFS) related geopolymer concrete at cured ambient temperature [2]. concentration of activators have an effect on the compressive strength of pozzolan-based geopolymer mortars. The soluble silicates increased the curing age strength. Strength diminishes as the water/pozzolan ratio increases, whereas flowability improves [3]. With increasing fineness values of the components, geopolymer concrete of high strength with tremendous compressive strength more than 65 MPa is achieved [4]. Geopolymer concrete had a low modulus of flexibility and Poisson's proportion values that were equivalent to those of conventional concrete. The microstructural properties and compressive strength of geopolymer glues were improved by the expanded solution of CSH on expanding the GBFS content. Utilising NH and NHNS solutions produced crystalline CSH and shapeless gel, whereas activating the NS solution produced amorphous products [5]. The ferrocement structural panels and RC beams exhibit greater capacity as compared to load-bearing RC beams and stone panels of the same thickness. Similar to this, brittle failure was only seen in sandstone roof slabs, but ductile failure was practised by the ferrocement roof slab system [6]. The mechanical and durability performances of alkali activated slag (AAS) mortar made with NH or PH and NS as the alkali activation mixes, 2% and 4% dosage of Nano silica, 5%, 7.5%, and 10% of Silica fume, and 2% and 4% dosage of Nano silica [7]. The compressive strength of geopolymer mortar rose with an increase in the GGBS concentration. Finally, they came to the conclusion that the ideal mortar mix ratios were 2.5 Na_2SiO_3 to NaOH and a 1:2 binder to sand ratio. Initial load cracking, ductility factor, and absorbed energy tend to rise as the amount of meshed steel does as well [8]. The ideal mixture should contain 5 mas. % of cement substituted with silica fume to achieve water tightness. When compared to the reference mixture, 33 mas. % cement substituted with metakaolin was found to be significantly less reactive in the depth of water absorption, resulting in a 10 percent decrease [9]. The durability and physical properties of geopolymer mortar including fly ash, GGBS, nanosilica, and ferrocement are thoroughly reviewed. Nano silica is also used in this research to improve the characteristics. As a result, it provides a framework for comprehending the benefits of employing Nano silica [10]. The parameters like first crack and ultimate failure energy absorption capacity, ultimate crack resistance, crack resistance ratio, ductility indices, and failure pattern were examined. The test results reported that the incorporation of binary blends of silica fume and slag in SIFCON matrix shows better performance in terms of strength and durability characteristics [11]. Flexural behavior including first crack loads and deflections, ultimate loads and deflections, ductility index, strain characteristics, crack pattern and failure mode were investigated. Effect of different types of core materials and mesh reinforcement on the flexural behavior of studied beams was investigated. Ferrocement beams of light weight cores may be promising as an alternative to conventional beams especially for low cost residential buildings [12]. It was observed the corrosion inhibiting property of fly ash and polymer ferrocement was remarkably improved with an increase from 0% to 30% of fly ash, 0% to 12.5% of polymer and decreased with specific surface of reinforcement [13]. The DIC results also indicate that incorporating 10% LECA leads to the highest increase of energy absorption (about 48%), ductility index (about 26%) and crack width (about 106%) of the FSPs. The results of microstructural analysis show that incorporating super-plasticizer admixture can decrease the total porosity of mixtures (by about 29 - 79%) [14]. The amount of reinforcement ratio and mortar strength were varied as the test variables. An analytical model was also developed to predict the cracking and ultimate moment of strengthened stone slabs. The unstrengthened specimen failed suddenly in a brittle fashion; however, the strengthened stone slabs experienced a ductile failure mode and developed a higher flexural strength [15]. The total reactive content of fly ash used in the current study is about 68.80%, similar to the amorphous content (66.28%) obtained using quantitative XRD and XRF. The values of reactive Si/Al ratios are between 2.65 and 2.98 depending on the duration of dissolution [16]. Geopolymers, although they contained high concentrations of alkalis, were more able to resist ASR than OPC was, and no characteristic swelling or any significant loss of rigidity was observed for the geopolymer specimens [17]. The geopolymer sample with a water/ash ratio of 0.2 shrinks 2.0% in the longitudinal direction after 500 °C heating, while it expanses 9.4% after 800 °C heating. In addition, it is found that the studied geopolymer possesses good spallation resistance when cooled down in water after high temperature heating [18]. The strength behavior of flat and folded fly ash based geopolymer ferrocement panels under flexure and impact is limited, notably the adaptability of geopolymer mortar in structural applications [19]. Alkali activated materials differ from OPC in terms of microstructure and reaction products, which means that they will have distinct evaluation processes and corrosion mechanisms. It may be made more carbonation resistant by increasing the MgO and activator content of the slag or lowering the calcium content of low calcium fly ash. From the review, it was suggested that CO_2 1% and RH 65 5% be used to obtain trustworthy and typical results. It was also suggested that raw material chemical and physical characteristics be taken into account, and that one should evaluate the longer-term durability properties rather than boosting test values with more concentrated CO_2 or salty solutions in the testing facility [20]. Fly ash and Nano silica were added to geopolymer mortar in place of cement in the structural elements to study the replacement suitability of GGBS and create an environmentally acceptable substitute. The ideal blend of this geopolymer composition and perfect by the addition of Nano silica to create the ideal blend. The flexural properties of a geopolymer cement slab wound with CFRP using welded wire mesh with different depths and layers and CFRP windings.

2 MATERIALS AND METHODS

2.1 Materials Used

Finely aggregated materials, sodium silicates, ground granulated blast furnace slag (GGBS), sodium hydroxide, CFRP (carbon fibre reinforced polymer), nano silica, cement, super plasticizer, wire mesh and fly ash are only a few of the components used in the study. The investigation's materials are gathered from the appropriate locations. The neighboring thermal power plant, commercial chemical store, local steel industry, and industries producing fly ash, nano silica, and GGBS, respectively, supply the raw materials. Crushing of rocks are used to extract fine aggregates. Superplastizer, sodium silicate, and sodium hydroxide are sourced from the chemical sector.

Mix Proposition:

This trial mix design was generated with the mortar density set at 2200 kg/m^3. The binder to fine aggregate ratio was established at 1:2 in accordance with ACI guidelines. Binder material accounted for 737 kg/m^3 of the overall density of the mortar, whereas M-sand sand accounted for 1463 kg/m^3. Geopolymer is chosen as the binder material. The components required for mortar per cubic metre are shown in Tab. 1.

Table 1 Optimized Geo Polymer binder with Nano Silica

Mix No	Fly Ash / kg/m^3	GGBS / kg/m^3	$(Na_2O)x\cdot SiO_2$ / kg/m^3	NaOH / kg/m^3	M-Sand / kg/m^3	SP /%	Mortar Ratio	Liquid to powder	Na_2SiO_3/ NaOH	Molarity of NaOH solution	% addition of Nano Silica
GFG 4	92.12	368.49	197.41	78.96	1463	0.4	1:2	0.6	2.5	10 M	0
GFGS1	92.12	368.49	197.41	78.96	1463	0.4	1:2	0.6	2.5	10 M	0.5
GFGS2	92.12	368.49	197.41	78.96	1463	0.4	1:2	0.6	2.5	10 M	1.0
GFGS3	92.12	368.49	197.41	78.96	1463	0.4	1:2	0.6	2.5	10 M	1.5
GFGS4	92.12	368.49	197.41	78.96	1463	0.4	1:2	0.6	2.5	10 M	2.0

GFS4 - Geopolymer, Flyash and GGBS mix 4; GFGS1- Geopolymer, Flyash, GGBS andSuper Plasticizer mix 1; GFGS2 - Geopolymer, Flyash, GGBS andSuper Plasticizer mix 2; GFGS3 - Geopolymer, Flyash, GGBS andSuper Plasticizer mix 3; GFGS4 - Geopolymer, Flyash, GGBS andSuper Plasticizer mix 4.

2.2 Methods

1. Strengthening of Ferrocement Slabs with CFRP Composites.

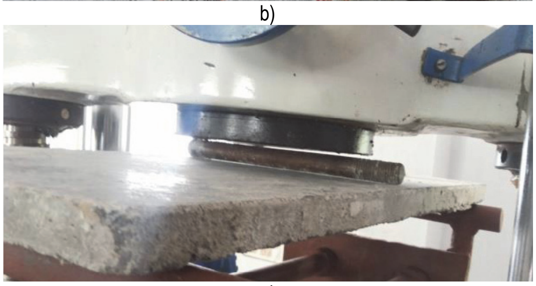
High strength, exceptional corrosion resistance, ease of handling, and minimal unit weight are just a few of the benefits of CFRP. CFRP systems are effectively utilised to reinforce the concrete. While restoring and bolstering the existing structures, an increase in the shear resistance of the reinforced concrete sections was necessary. CFRP is made up of a polymeric matrix that includes reinforcing fibre and functions as a composite material. Fibre offers stiffness and strength, whereas resin offers a matrix to transfer the load to the fibres, provides stability, and creates a surface that is chemically resistant. Composites made of CFRP that are bonded externally can enhance the performance of structures, including their ability to support loads, performance under fatigue and cyclic loading, infrastructure durability, ductility, and stiffness.

2. Installation of CFRP strengthening system in ferro cement slab.

To create CFRP threads, 1.2 mm thick CFRP mats are used. The CFRP is then wound in wire mesh along the longitudinal span. Fig. 1a, Fig. 1b and Fig. 1c shows how to apply CFRP to support the concrete slab as it is being casting and testing.

a

b)



c)

Figure 1 a) Installation of CFRP, b) Cast specimen c) Testing of specimen

2.2 Compression Strength Testing

Compression strength, a qualitative property, may be used to quantify mortar qualities. At 3, 7, and 28 days, the cube specimens of size 50 mm that were cast for each percentage are evaluated under compression force.

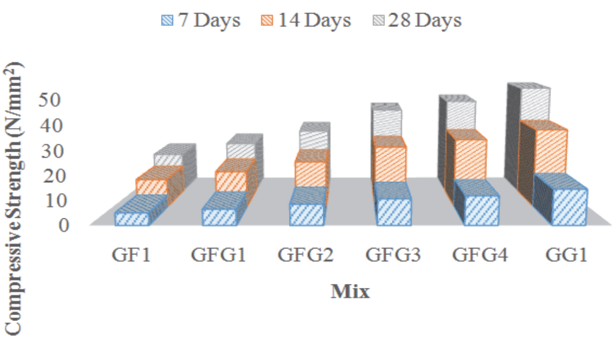


Figure 2 Geo polymer binder-based trial mix with varying fly ash and GGBS content under room temperature

Three cubes per combination are tested in these tests. Geopolymer-based cubes are heated to 60 °C or cured at room temperature. In a machine intended for measuring compression, the specimens are tested using a 2000 kN capacity in accordance with IS 516 (1959). The compressive strength of ferro cement mortar for various arriving trial mixes is shown in Fig. 2 and Fig. 3 under open air curing conditions. Similar to Fig. 4, Tab. 5 shows the experimental mixtures under high curing conditions heated to 60 °C.

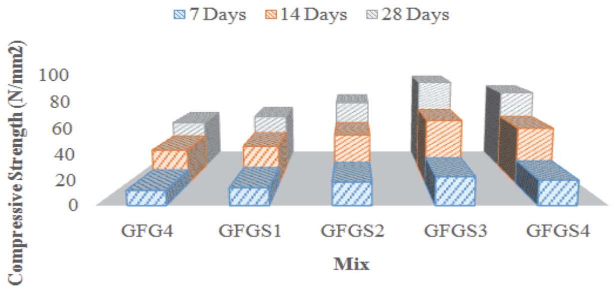


Figure 3 Optimized geo polymer binder with nano silica under room temperature

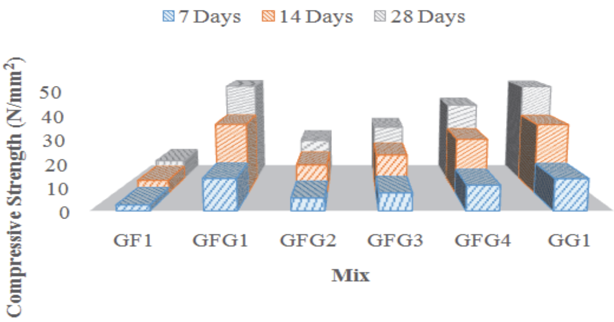


Figure 4 Geo Polymer binder-based trial mix with varying fly ash and GGBS content (hot curing)

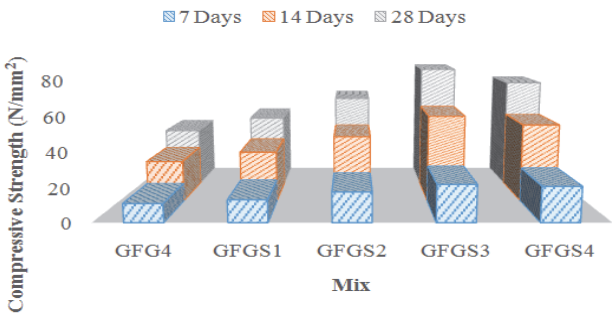


Figure 5 Optimized geo polymer binder with nano silica (hot curing)

2.4 Durability Properties

The primary elements that impact the durability of ferro cement slabs are wire mesh, corrosion, chemical assault, concrete spalling at different temperatures and cavitation. The following circumstances will not affect the durability of ferro cement mortar, the cement paste is thick and has little permeability, strong and inert Nano materials are used to produce mortar, together with fine-grained aggregate and there should not be many contaminants in the combination. The contaminants include sulphate, chloride, and alkaline. Durability is the quality of persisting for a prolonged period of time without noticeably changing. Using a durable material helps to decrease trash disposal and save environmental resources. Even after coming into touch with the atmosphere, durable ferro cement material retains its functionality, quality, and nature. Acid tests, water permeability tests, and thermal tests are carried out with durability being a key criteria.

Water Permeability Test:

IS 3085 - 1965 Method for permeability analysis of concrete and cement mortar is used to assess the permeability of ferro cement mortar. The permeability of ferro cement mortar may be determined using one of two approaches. They are method of steady flow and penetration depth technique. If the permeability is high, use the steady flow approach; otherwise, use the penetration method. The test involves applying a known hydrostatic pressure to one side of a mortar specimen and measuring the amount of water that passes through it in a certain time while determining the coefficient of permeability. To evaluate the coefficient of permeability, 150 mm cube specimens are cast with varied quantities of mixes and cured for 28 days. The specimens are housed in a permeable cell after being cured for 28 days and covered with water resistant material on all sides except the top and bottom. An elastic sheet 8mm thick and 150 mm × 150 mm in size is secured on both sides of the specimen in a permeable cell, with a central hole 100 mm × 100 mm. The cover plate is correctly fastened. The desired test pressure is applied when the water reservoir has been fully filled. Four more days are added to the permeability test. The cubes are broken in half, the depth of permeation is measured, and the penetration depth is used to calculate the permeability coefficient (*kp*) if there is no permeation.

Acid Resistance Test:

In this study, the acid resistance of mortar is tested using the ASTM C267 test technique. The cubical type specimens of ferro cement mortar with changing mortar mix of size 5 cm are cast, and the specimens are exposed to acid immersion 5 days after air and heat curing. The weight of a cubical specimen of ferro cement mortar is recorded. The mortar cubes are analysed using an acid attack, which involves immersing the cubical specimens in hydrochloric acid with a pH of 2 for 28 days. After removing the specimens from acid immersion, the compression strength is computed. The specimens are then compressed strength tested. By comparing the ratio of the specimen's mass loss to its compression strength loss after being submerged in acid water, ferro cement mortar's resistance to acid attack is evaluated.

Thermal Resistance Test:

The cubes are de-molded and stored in the appropriate environment for 28 days. The specimens are then cooked in an oven set to less than 200 °C. After 24 hours of heating, the specimens are immediately placed in an axial machine and weights are applied.

Ultrasonic Pulse Velocity Test:

To make sure the quality and homogeneity of panels, ultrasonic pulse velocity test was performed. This test was carried out by sending ultrasonic pulse through the panels and the time taken for the pulse to pass through was measured. The ultrasonic pulse was sent along the grids by keeping transducers/probes on the marked locations. High material quality and continuity are denoted by higher velocities, and cracks or cavities are denoted by lower velocities.

3 RESULTS AND DISCUSSION

3.1 Permeability Test

The permeability tests were conducted for both curing at room temperature and hot curing that's curing at 60 °C. The depth of penetration calculated on specimen from the permeability test is depicted as graphical representation and provided in Fig. 6.

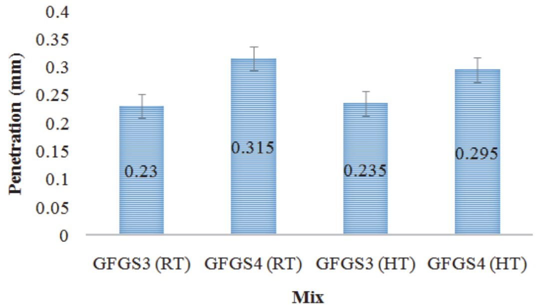


Figure 6 Penetration depth of permeability test

3.2 Acid Resistance Test

The Acid resistance test was conducted for both curing at room temperature and hot curing that is curing at 60 °C. The percentage of loss of weight of the specimen is depicted as graphical representation and provided in Fig. 7.

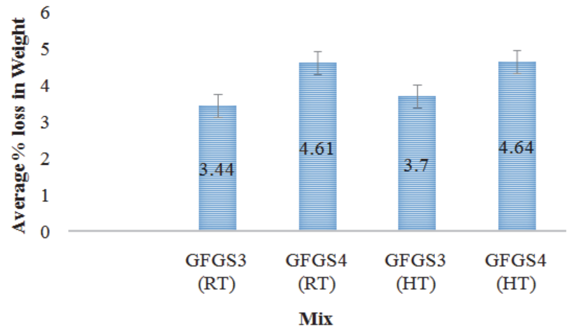


Figure 7 Percentage of loss of weight

3.3 Thermal Resistance

Fig. 8 shows four different graphical representations of the specimens for thermal resistivity at different curing condition. It also shows the stress value of specimens subjected to thermal effect for normal temperature curing and hot curing.

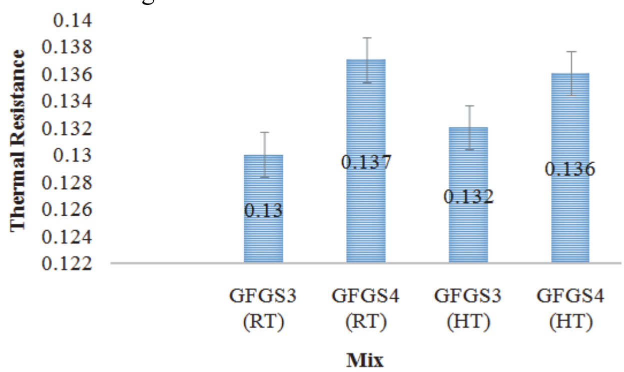


Figure 8 Thermal resistivity

3.4 Ultrasonic Pulse Velocity Test

To make sure the quality and homogeneity of panels, ultrasonic pulse velocity test was performed. This test was carried out by sending ultrasonic pulse through the panels and time taken for the pulse to pass through was measured. Fig. 9 shows the flow diagram of ultrasonic pulse velocity test. For accuracy of results, grids are marked on the sides of the panels as shown in Fig. 10 and the ultrasonic pulse was sent along the grids by keeping transducers/probes on the marked locations. High material quality and continuity are denoted by higher velocities and cracks or cavities are denoted by lower velocities.

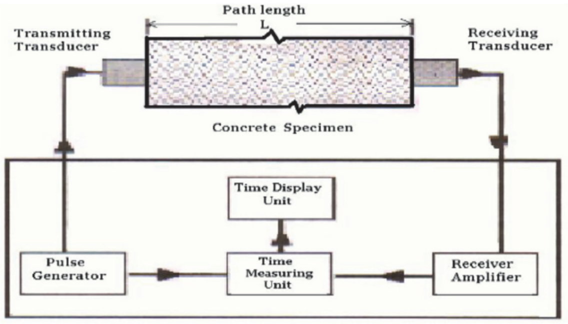


Figure 9 Ultrasonic pulse velocity

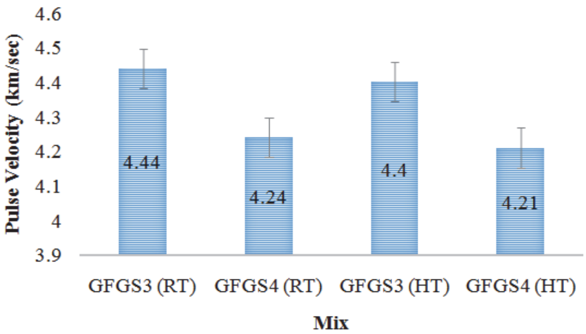


Figure 10 Ultrasonic pluse velocity test

5 CONCLUSION

The mix with 80% GGBS and 20% of fly ash is concluded as the optimized mix even though 100% of GGBS gained optimum and the strength for optimized mix is increased to 329% from the control specimen at open air curing condition and 143% at hot curing condition. At 100% of GGBS, some small cracks are found over the surface of the cube specimens which is not advisable for slabs. By adding the Nano silica mix, the pores of mortar specimen are found to get arrested. The strength is increased by 114% and 91% from the optimized mix with 1.5% of Nano silica under open curing condition and hot curing conditions respectively. By adding nano silica and GGBS the curing times have been reduced to a greater extent. The strength and durability property of the ferrocement geopolymer cement attends maximum strength with room temperature curing which neglects the problem of hot curing. The GFGS 3 mix at room temperature gives the best results in all the durability aspects, namely, permeability test, acid resistance, thermal resistance and ultrasonic pulse velocity. The permeability of GFGS 3 mix resists water, acid resistance, thermal resistance and ultrasonic pulse velocity of about 85%, 109%, 125% and 113% compared to the conventional ferrocement and 37%, 34%, 5% and 6% compared to the GFGS 4 mix. Therefore the GFGS 3 mix is the superior mix compared to all other mixes. Incorporation of nanosilica, GGBS and flyash increase the properties of geopolymer ferrocement even in the normal curing temperature. The amount of wire mesh layers increases the strength of ferro cement slabs. When three layers of welded mesh were used instead of a single layer, the strength improved by approximately 48%.

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