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Experimental Investigation on GGBS and Nano Silica Based Fiber Reinforced Geopolymer Concrete

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Abstract

Concrete is the most useful material for building. It is made up of different parts, such as ordinary Portland cement (OPC), fine aggregate, coarse aggregate, and water. In addition, some of the mineral admixtures were added to the concrete to help it work better. Due to huge needs of building industry, the amount of Portland cement made has been growing at a faster rate every year. Even though this huge amount of OPC production uses a lot of energy and contributes to global warming by releasing carbon dioxide. On the other hand, a lot of industrial waste is dumped in the land and sea. In this the geopolymer concrete is made from materials that come from the earth and by-products of industry, such as fly ash and ground granulated blast furnace slag (GGBS), which is high in alumina and silica. The main goal of the geopolymer concrete study was to describe the mechanical properties of geopolymer concrete and strength prediction of compressive strength was done with the help of Python. In this study, fly ash, GGBS, nano silica (NS), sodium hydroxide (NaOH), sodium silicate (Na_2SiO_4), M-sand, and natural coarse aggregates were used to make geopolymer concrete. Also, 0.25 and 0.5% of steel fibers with an aspect ratio of 60 and 70 were added to the mix. So, the focus of this study is on how adding steel fibers to geopolymer concrete affects its mechanical features, such as its compressive strength, split tensile strength, flexural strength, impact strength, and modulus of elasticity.

Keywords

Geopolymer concrete, Flyash, Ground granulated blast furnace slag, Nano silica, M-sand, Steel fiber, Mechanical strength

Introduction

Geopolymer is the name given to the cementitious substance that is generated when an alumino-silicate base is activated in high alkali solutions [1, 2]. The idea of using geopolymers as a new and innovative binder material in concrete that has features that are sustainable and friendly to the environment has only recently gained traction [3]. It is common knowledge that the activation of aluminosilicates by alkalis can result in the formation of geopolymers or X-ray amorphous alumino-silicate gels, both of which have favorable chemical and mechanical properties [4, 5]. To make mortars and concretes, these gels are used as a binding agent for the fine and coarse material. Inorganic binding compounds known as geopolymers function similarly to Portland cement in their application [6]. The skeleton of the geopolymer gel is made up of tetrahedral alumino-silicate structures that have their charges neutralised by alkali cations.

The use of the name "geopolymer" in no way implies that polymers were involved in the manufacturing of geopolymer concrete [7]. As these source materials react with alkaline activator solutions, polymerization takes place to give rise to geopolymer gel with the heat energy [8]. The amount of silica and alumina that are present in some of the source materials is high [9]. Some examples of these materials include metakaolin clay, fly ash, and rice husk ash, among others. Davidovits, a professor of chemistry at the time, came up with the idea of geopolymer concrete in 1978. At the same time, he made the discovery that a geopolymer matrix could be employed as a binder in concrete rather than cement [10, 11]. According to the theory that was proposed by Davidovits, a geopolymer binder can be manufactured by adding an alkaline solution to a source material that is abundant in silica and aluminum [12]. This should result in the production of the geopolymer binder [13] declared that, with a dose of 4% nanoparticles, the durability and strength properties of the concrete had improved the most. The incorporation of NS facilitated the generation of additional calcium-alumino-silicate-hydrate (C-A-S-H) gel by its reaction with the calcium constituents present in fly ash, leading to enhanced compaction within the matrix. The microstructure of geopolymer concrete was enhanced because of the creation of more C-A-S-H gel [14].

The thermal power plant that runs on coal generates a waste called fly ash [15]. It possesses several desirable qualities on both the physical and chemical levels. The amount of calcium that is contained in fly ash is rather low [16-18]. Fly ash experiences a lower rate of loss during the ignition process. Fly ash is one of the most common components utilized in the production of geopolymer concrete [19, 20]. This is because of the qualities described above. Blast furnace slag, rice husk ash, natural alumino silicate minerals, and metakaolin are some examples of additional additive materials that are high in silica and alumina content [21]. These materials are also capable of serving in the capacity of a binder in geopolymer concrete.

Conventional concrete uses fibers to improve mechanical qualities. Steel, glass, carbon nano, banana, palm leaf sheath, polypropylene, and other fibers have been investigated. Fibers improve concrete qualities; however, they have limitations [22, 23]. In corrosive environments, steel fibers reduce concrete durability, especially when it splits. An optimal fiber dose also improves concrete qualities. Thus, geopolymer concrete mixes with steel fibers require additional care. Due to their affordability, density, tensile strength, and availability, steel fibers are utilized to make composite materials [24]. Previous studies have recommended 30 - 80 aspect ratios for steel fibers. Thus, this study evaluated aspect ratios of 60 and 70 with geopolymer concrete compositions of 0.25 and 0.5%. In this work, the artificial neural network (ANN) model was adopted because of its unique capability in nonlinear mapping, which can save significant time and money compared to traditional laboratory methods for evaluating the compressive strength of concrete.

Materials and Method

Materials

Fly ash

Thoothukudi Thermal Power Plant in Tamil Nadu, India provided the low calcium fly ash (Class F) that was used for this experimental work. This fly ash has a low calcium concentration and comes from a source with a low calcium content.

GGBS

As the secondary binder, GGBS, was utilized. The GGBS was acquired from a market that was available locally. The readings for the specific gravity were 3.11, and the value for the fineness was 2.91.

NS

NS that was readily available in the industry was identified and it was utilized. The specific gravity of NS is 2.42.

Fine aggregates

As the fine aggregate, M-sand that was readily available in the area was utilized. It is not being stopped by the 4.75 mm sieve. The specific gravity is 2.56 and fineness modulus is 2.6.

Coarse aggregates

In this current investigation, a coarse aggregate that measured a maximum of 12 mm in size was utilized. The specific gravity of the coarse aggregate is 2.79 and fineness modulus is 6.6.

Alkaline activators

For the preparation of the alkaline activator solution, the source materials that were utilized were NaOH and Na_2SiO_3. Both compounds are offered for sale in commercial quantities on the market.

Super plasticizer (SP)

The addition of the sulphonated naphthalene polymers-based SP Conplast SP 430 was made to the binder to provide the geopolymer concrete with the appropriate workability when it was in the fresh stage. The SP was brown in color, and it quickly disintegrated in water once it was exposed to the liquid.

Water

To make the NaOH solution and reach the necessary molarity, distilled water was employed. Additionally, a quantity of potable water was added to the mixture to get the desired level of workability.

Steel fibers

Salem, India was the location where the low carbon cold drawn hooked end steel fibers were acquired. These fibers have a modulus of elasticity of 2×10^5 MPa, a density of 7850 kg/m^3, a yield strength of 650 MPa with the tensile strength of 1100 MPa. The length/diameter ratio of 60 and 70 was used.

Mix proportion and quantity of geopolymer concrete is shown in table 1 and table 2.

Experimental investigations

Compressive strength

Table 1: Mix proportion of GPC.

Specimen	Fly ash %	GGBS %	NS %	SP %	Steel fiber %	Aspect ratio
GPC	100	-	-	5	-	-
GPC1	95	2.5	2.5	5	-	-
GPC2	90	5	5	5	-	-
GPC3	85	7.5	7.5	5	-	-
GPC4	80	10	10	5	-	-
GPC5	75	12.5	12.5	5	-	-
GPC6	70	15	15	5	-	-
FGPC1	75	12.5	12.5	5	0.25	60
FGPC2	75	12.5	12.5	5	0.5	60
FGPC3	75	12.5	12.5	5	0.25	70
FGPC4	75	12.5	12.5	5	0.5	70

Figure 1: Compressive strength test setup.

The compressive strength of the concrete was used as the criterion for determining the strength of the concrete. The cube specimens with dimensions of 150 mm on each side were evaluated following the prescribed length of curing time. The compression test setup for the cube is depicted in figure 1. The samples were put through compression testing using a machine that had a capacity of 2000 kN and could load at a rate of 150 kN per minute. The specimens were loaded all the way up until they broke, and then the maximum load was measured and recorded. The procedures were performed on three different samples, and an average of the compressive strengths of each was determined.

Figure 2: Split tensile test setup.

Split tensile strength

Split tensile strength was used to measure the tensile strength of geopolymer concrete (GPC) and fiber reinforced geopolymer concrete (FRGPC). Cylindrical samples with a height of 300 mm and a width of 150 mm were cast and put through a 2000 kN compression testing machine. The cylinder was kept horizontal in the machine, and two steel plates were put at the top and bottom of the cylinder along its length. The load was slowly added until the sample broke, and the final load was written down. Three samples were used for the tests, and the average split tensile strength was recorded. The split tension test is shown in figure 2.

Impact strength

The impact resistance of GPC and FGPC was evaluated by performing the repeated impact test and its setup is shown in figure 3. In this test, the specimens were exposed to impact by a known weight of 45 N which was dropped freely from a vertical height of 450 mm. The disc specimen was placed under the hammer, and the load was transferred through the 64 mm diameter steel ball put in the center of the disc.

The number of hits that were used to cause the first crack and the final failure of the sample were counted and written down. The final failure was taken to mean that the disc completely split open, and the first crack strength and the end crack strength were calculated.

Modulus of elasticity

The results of the test on the cylindrical object were used to figure out the modulus of elasticity of GPC and FRGPC.

Table 2: Mix quantity of the GPC (kg/m^3).

Specimen	Fly ash	GGBS	NS	Fine aggregate	Coarse aggregate	NaOH	Na_2Sio_3	Water	SP	Steel fiber
GPC	393	0	0	552	1288	46	111	58	13	0
GPC1	373	10	10	552	1288	46	111	58	13	0
GPC2	354	19	19	552	1288	46	111	58	13	0
GPC3	334	29	29	552	1288	46	111	58	13	0
GPC4	314	40	40	552	1288	46	111	58	13	0
GPC5	295	49	49	552	1288	46	111	58	13	0
GPC6	275	118	59	552	1288	46	111	58	13	0
FRGPC1	295	49	49	552	1288	46	111	58	13	0.2
FRGPC2	295	49	49	552	1288	46	111	58	13	0.4
FRGPC3	295	49	49	552	1288	46	111	58	13	0.2
FRGPC4	295	49	49	552	1288	46	111	58	13	0.4

Figure 3: Impact test setup.

Figure 4 shows the test set-up. All the test samples were put through axial compression using a digital compression testing machine with a load limit of 2000 kN. The compress meter was made up of two frames with tightening screws held by two spacer rods, a tension spring with a ball chain, and pivot screws with one pivot rod. A dial gauge was used to measure the pressure along the length of the cylinder.

Figure 4: Modulus of elasticity test setup.

Flexural behavior

As can be seen in figure 5, all the beam samples were evaluated using a loading frame with a capacity of 25 tons. The beam specimen was merely held up by two rollers that were spaced 1500 mm apart from one another. In this test, the specimens were loaded from two different points simultaneously. There was a space of 500 mm between the two loading points from each support. To monitor the beam's deflection, three linear variable differential transducers were positioned under the loading point and in the beam's center. A load cell with a capacity of 500 kN was used to measure the associated load while the load was gradually added with the help of a hydraulic jack that could be manipulated by hand. The load was delivered in increments of 2.5 kN, and the linear variable differential transducers' readings of the associated deflections were recorded at regular intervals. In addition, deflections and the spread of cracks were measured and recorded at each stage of the loading process. The specimens were loaded up to their ultimate strength, and the failure manner was examined as it occurred. The structural parameters of ductility were computed based on the load-deflection characteristics of the material.

Figure 5: Flexural strength test setup.

Results and Discussion

Compressive strength

The outcomes of the compressive strength test are displayed in figure 6. The most important property of concrete is compressive strength. The geopolymer concrete mixes are built in such a way that the fibers are partially replaced by 0.25

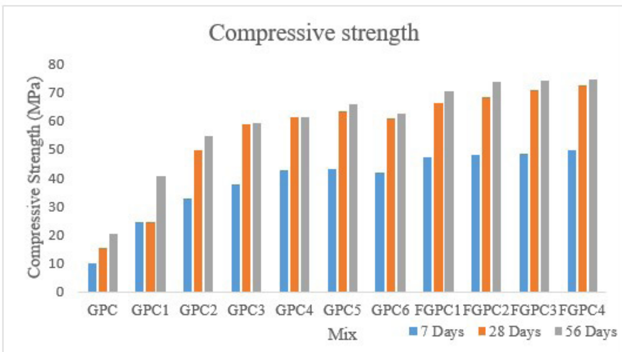

Figure 6: Test results on compressive strength.

and 0.5% with a combination of fly ash, GGBS and NS. This occurs at various percentages throughout the mix. To assess the compressive capacity of a material, cubes are measured using a compression testing equipment. The compressive strength test, also known as the compressive resistance test, is often utilized to ascertain the compressive strength of a concrete specimen. In proportion to the length of time that has passed since the concrete was placed, the compressive strength of the concrete has grown from 7 days to 56 days. In a composite, the proportion of NS ready for reaction increased as the volume fraction of nanoparticles in the composite increased. The combination of fly ash, GGBS with NS increases the microstructure and density of the concrete. The average compressive strength of the material ranged from 10.1 MPa, 15.2 and 20.2 MPa to 49.5, 72.6 and 74.5 MPa after 7 days, 28 days, and 56 days of curing, respectively. The use of steel fibers has resulted in a significant increase in the strength of the geopolymer concrete. The improvement in compressive strength that can be attributed to the insertion of steel fibers is the result of several different variables working together.

The results of the compressive strength test are shown in table 3, which effectively slows the spread of cracks. However, there is an optimal dose of fibers that will benefit the compressive strength, and in this investigation, 0.5% was reported to be the optimal dose. Compressive strength is increased for a number of reasons when steel fibers are added. Fiber addition, for instance, enhances concrete's compressive strength by increasing its density. Steel fibers improve the connection between the fibers and the concrete mix.

Table 3: Test results on compressive strength.

Mix	Compressive strength (MPa)		
	7 days	28 days	56 days
GPC	10.1	15.2	20.2
GPC1	24.5	24.4	40.4
GPC2	32.8	49.8	54.6
GPC3	37.7	58.6	59.2
GPC4	42.6	61.2	61.3
GPC5	43.2	63.4	65.8
GPC6	41.8	60.7	62.4
FGPC1	47.1	66.2	70.5
FGPC2	48.2	68.1	73.6
FGPC3	48.6	70.7	74.2
FGPC4	49.5	72.6	74.5

Comparison of the observed compressive strength of concrete with the calculated one using the regression model of geopolymer concrete is shown in figure 7. Based on performance criteria such as normalized mean square error, coefficient of determination, and correlation coefficient, it is evident that ANN is superior from the point of view of accuracy, correctness, and eye-catching flexibility of this structure in dealing with multidimensional, nonlinear, complex problems such as estimation of compressive strength parameter. This is confirmed by the fact that ANN is superior. The generalization property of ANN has also been used in forecasting the amounts of compressive strength based on the collected data. These results, which are proof of the reliability

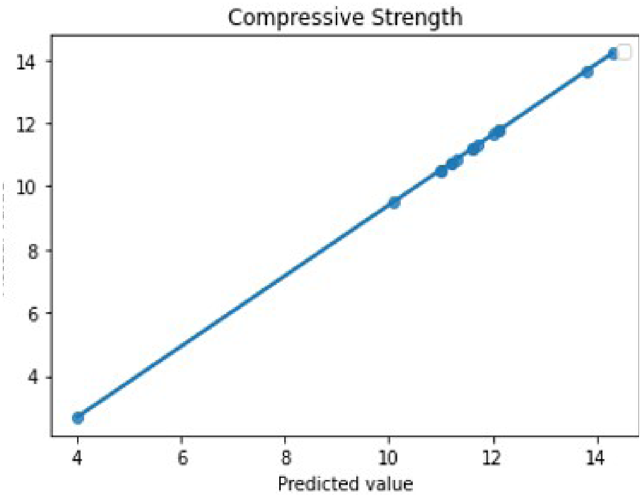

Figure 7: Strength prediction using regression model.

of the suggested technique in this study, were used as the basis for this prediction.

Split tensile strength

The information regarding the split tensile strength of specimens that were produced with the replacement of fly ash, GGBS with NS in different proportions, at the age of 28 and 56 days under steam curing, may be found in table 4 and figure 8, respectively. It was shown that there is a correlation between age and a rising trend in the split tensile strength. after 28 days, the split tensile strength of GPC specimens can range anywhere from 0.96 MPa to 4.21 MPa, and after 56 days, it

Table 4: Test results on split tensile strength.

Mix	Split tensile strength (MPa)	
	28 days	56 days
GPC	0.96	1.32
GPC1	2.3	2.5
GPC2	2.7	3.02
GPC3	2.9	3.15
GPC4	3.2	3.4
GPC5	3.4	3.6
GPC6	3.1	3.3
FGPC1	3.5	3.7
FGPC2	3.6	3.9
FGPC3	3.73	4
FGPC4	4.21	4.35

Figure 8: Test results on split tensile strength.

can range anywhere from 1.32 MPa to 4.35 MPa. The average split tensile strength at 28 days and 56 days is the same as what other researchers have found [21].

The test results depict that the split tensile strength of GPC specimen increases with respect to the increase in the content of GGBS and NS combination. The strength gain shows a similar trend to that of the development of compressive strength. Compared to specimen without fiber, specimen with fiber demonstrate better split tensile strength at all ages. The primary explanation for the improvement in split tensile strength is that steel fibers make geopolymer concrete better at holding its shape when pulled apart. Also, this gain is better than an increase in compressive strength, because tensile forces cause fibers to stretch and strain more. As a result, fibers actively help spread the load and improve the tensile strength of the gopolymer concrete.

Impact strength

It has been determined by conducting research that the performance of GPC and FRGPC specimens is affected by the incorporation of steel fibers in a variety of aspect ratios and volume fractions. To determine the impact strength, disc specimens were employed. The findings of the tests conducted on specimens when they were 56 days old are provided in table 5 and figure 9, respectively. These results refer to the first crack strength and the failure strength. It was discovered that the GPC1 specimen broke in a brittle fashion, whereas the FRGPC specimen broke in a ductile manner when it failed. According to the findings of the tests, the crack resistance of the FRGPC specimen is significantly higher than that of the GPC1 specimens. When compared to the GPC1 specimen, the first crack strength of the FRGPC specimen is marginally superior to that of the GPC1 specimen.

Table 5: Test results on impact test.

Mix	Impact strength (Nm)	
	First crack strength	Failure Strength
GPC	1160	1265
GPC1	1226	1485
GPC2	1436	1586
GPC3	1706	1852
GPC4	1963	2088
GPC5	2008	2216
GPC6	1957	2094
FGPC1	2120	2218
FGPC2	2198	2306
FGPC3	2286	2478
FGPC4	2384	2896

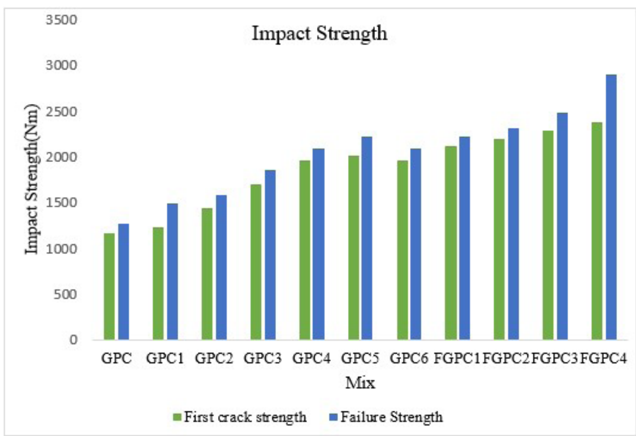

Figure 9: Test results on impact test.

Modulus of elasticity

At the age of 56 days, the results of the stress-strain analysis were used to take a measurement of the longitudinal strain. The addition of steel fibers in it results in a rise in compressive strength, which in turn leads to an increase in the material's modulus of elasticity. The specimen of type GPC6 had a modulus of elasticity of 27041 MPa, while the FRGPC4 test yielded the highest possible value of 31288 MPa for this parameter. Table 6 and figure 10 exhibit the effects of aspect ratio and volume percentage of steel fibers on the modulus of elasticity of GPC and FRGPC specimens, respectively. The findings of the tests indicate that the incorporation of steel fibers into the FRGPC specimen results in an increase in the specimen's modulus of elasticity in comparison to the GPC specimen.

Table 6: Test results on modulus of elasticity.

Mix	Modulus of elasticity (MPa)
GPC	24872
GPC1	25431
GPC2	26543
GPC3	27258
GPC4	28057
GPC5	28563
GPC6	27041
FGPC1	29547
FGPC2	30095
FGPC3	30107
FGPC4	31288

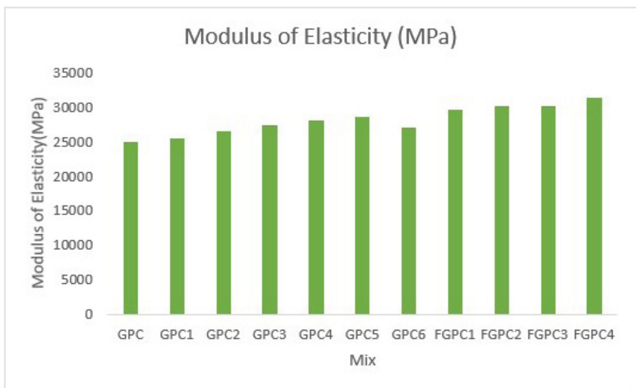

Figure 10: Test results on modulus of elasticity.

3.5. Ductility

The ratio of the maximum deformations (u) of a concrete specimen under any load level to the initial yield deformation (y) of the specimen is the definition of ductility. Ductility is measured in ratios. A bilinear trend was seen in the load-deflection curves that were used in this study, which allowed for the determination of the initial degree of concrete specimen deformation. Table 7 displays the absolute and relative ductility factors that were determined by computation for GPC and FRGPC beam specimens. The mechanical performance of the samples was best when 0.25 and 0.5% steel fibers were combined with 12.5% GGBS and 12.5% NS with 75% fly ash. Both the flexural strength and the fracture performance of geopolymer specimens saw substantial increases. The fracture bridging ability came from the steel fibers, whereas the increased adhesion and bonding came from the GGBS.

It can be deduced from figure 11 that the incorporation of steel fibers improves the ductility performance of beam specimens. Furthermore, it can be shown that an increase in the volume fraction and aspect ratio of steel fibers also results in an increase in the ductility value. The FRGPC4 specimen has the highest ductility value, which was determined to be 3.84. This value is 46.6% greater than what was determined for the GPC beam specimen. It has come to light that the incorporation of steel fibers into concrete at a larger aspect ratio increment results in an improvement in the ductile performance of the concrete.

Table 7: Test results on flexural behavior.

Mix	(Δu) mm	(Δy) mm	Ductility factor (Δu/Δy)
GPC	2.58	5.3	2.05
GPC1	2.61	5.8	2.22
GPC2	2.98	5.9	1.98
GPC3	2.71	6.2	2.29
GPC4	2.83	6.4	2.26
GPC5	2.85	6.8	2.39
GPC6	2.88	6.1	2.12
FGPC1	2.87	7.2	2.51
FGPC2	2.65	7.5	2.83
FGPC3	2.43	8.4	3.46
FGPC4	2.32	8.9	3.84

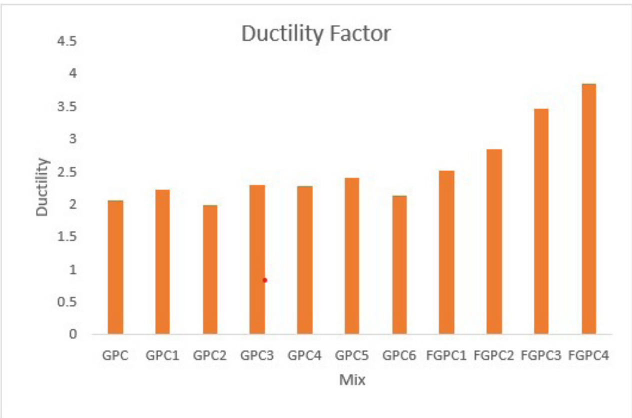

Figure 11: Test results on flexural behavior.

Conclusion

According to the findings of compressive strength tests conducted on heat-cured specimens, it was discovered that the GPC specimen had achieved the 28-day strength within three days of the curing process. This was made possible by the quick polymerization process and the creation of a robust polymer chain. From the research has been dedicated to integrating nanoparticles of NS into GPC to boost its performance and generate GPC with enhanced properties. The effort originates from the recognition that nanotechnology holds the potential to improve the capabilities of materials. In recent times, there have been endeavors to integrate different nanomaterials, with a particular emphasis on GGBS and NS into GPC to enhance the characteristics of the composite. The attribute of compressive strength holds significant importance in the evaluation of various concrete composites, including GPC. Therefore, the development of a reliable model for predicting concrete compressive strength is of utmost importance to optimize time, energy, and financial resources. Additionally, such a model would offer valuable insights for effectively organizing the building process and facilitating the removal of formworks. The findings of the tests indicate that the incorporation of steel fibers into FRGPC specimens in a variety of aspect ratios and volume fractions resulted in a considerable increase in the average density of FRGPC specimens in comparison to GPC specimens across all ages. When the FRGPC samples are subjected to heat curing, it is also seen that there is a slight difference in the density of the samples. Strength qualities, including as compressive strength, split tensile strength, and modulus of elasticity, are improved when steel fibers are incorporated into the GPC mix. At the ages of 7 days, 14 days, and 28 days, respectively, the FRGPC4 specimen achieved a maximum compressive strength of 49.5 MPa, 72.6 MPa, and 74.5 MPa. These values were realized about the specimen's compressive strength.

Increases in aspect ratio and volume fraction of steel fibers enhance the impact strength of FRGPC specimens to a greater extent when compared to GPC specimen and change the failure manner from brittle to ductile. This is shown by the impact strengths at first crack load and failure load of FRGPC4 specimens. Because of this, the inclusion of steel fibers in GPC enhances the material's capacity to absorb kinetic energy and slows the spread of cracks.

The increase in the aspect ratio and volume fraction of steel fibers in FRGPC specimens is directly correlated to an increase in the modulus of elasticity of the material. The specimen of type GPC6 had a modulus of elasticity of 27041 MPa, while the FRGPC4 test yielded the highest possible value of 31288 MPa for this parameter. When compared to the control concrete GPC specimen, it was increased by a quarter of a percentage point. Because steel fibers have a higher modulus, this improvement can be attributed to those fibers.

Acknowledgments

None.

Conflict of Interest

None.

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