Investigation on Micromechanical Behavior of High-Performance Fiber Concrete

N. Arivusudar and S. Sureshbabu

1 Introduction

Concrete is perceived as a delicate material when presented to standard burdens and effect loads. Its elasticity is only one-tenth of its compressive strength under such conditions [1]. The concrete flexural members also cannot perform under such loads during their life period [2–5]. The presentation of filaments is acquired as an answer to provide concrete with improved ductility and flexibility [6–9]. Plastics are regularly utilized substances that assume a significant job in each part of human lives [10–12].

The usage of plastics across ages needs legitimate reusing as well as the reuse of its executives [13]. The most noteworthy sum utilization of plastics has been found in holders and bundling of products since it is long lasting and removal merchandise. Removing different residues is not a kidding issue in the cutting-edge days. So, it ought to be settled possibly to stay away from such circumstances [14–16].

Concrete is the most flexible man-made material used in different constructional occasions. As a material, its usage in the world is second to water these days [17]. This is an immediate aftereffect of its mouldability, of which its quality and strength are viewed as the brand name when set. Strong development has made impressive strides in the previous decade [18]. Concrete is, as of now not, now, a material containing solid, aggregates, water, and admixtures; notwithstanding, it is an assembled material with a couple of new constituents [19].

There are no united definitions for High-Performance Concretes (HPC), while different institutions and experts out of the blue describe High-Performance Concrete [20]. The American Concrete Institute demonstrates High-Performance Concrete as “Strong that meets outstanding execution and consistency necessities that can’t happen by and large be obtained by using customary trimmings, conventional mixing

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technique, and normal calming practices." In less muddled words, HPC is a firm that has one exceptional property, viz regardless. Compressive strength, high workability, enhanced resistances to chemical or mechanical stresses, lower permeability, durability, etc., when appeared differently about conventional concrete [21]. For example, self-compacting concrete is a specific piece of high-performance concrete that isolates itself with self-association properties joined with high stream capacity.

2 Materials and Method

This part manages different solid materials' physical and compound properties, like concrete, good total, coarse total, flying debris, silica rage, GGBS, PVA fiber, PP fiber, and steel fiber and water. A conventional Portland concrete of 53 evaluations, adjusting to IS 8112–1989, was utilized. The industrially accessible stream sand, which has been removed from the waterway Cauvery, is being used as the fine total for this exploration. The Fine total is tested as per IS: 2386–1963 [22–24]. This fine aggregate is clean, with no clay and no chemical constituents in it. The other name of concrete is artificial stone since its volume around 75 to 85% is occupied by the crushed stone, i.e., coarse aggregate. These coarse aggregates are derived from the rock quarry. The maximum size of coarse aggregate that has been taken for this research is 20 mm. Fly ash is the environmental pollutant produced by the coal-based thermal power station, and it has the potential to be used as a resource material due to its properties. So this fine waste material is used in cement, concrete, and other cement-based applications. The chemical properties of GGBS are shown in Fig. 1.

Silica fume is the environmental pollutant produced by the coal-based thermal power station, and it has the potential to use as a resource material due to its properties. So this fine waste material is used in cement, concrete, and other cement-based applications. GGBS (Ground Granulated Blast heater Slag) is a cementitious material predominantly utilized in cement, and it is a result of the impact heaters used to make iron. Impact heaters work at about 1500 °C and are taken care of with a deliberately controlled combination of iron mineral, coke, and limestone. The iron mineral is decreased to press, and the excess materials structure a slag that coasts on top of the iron. Water is an essential ingredient in concrete to strengthen strength from cement gel enhancing through the hydration process. So, it is necessary to check its quality. The water used in concrete is to satisfy the standard of IS 456–2000.

2.1 Mix Proportions

A blend is planned according to IS 10262–2009 to accomplish the solid evaluation of M40. The created and embraced blend extent is 1:1.711: 2.867: 0.40. A steady water–concrete proportion of 0.40 has been utilized for all the blends. This concrete mix design gives the high-performance concrete, the silica fume is added with cement

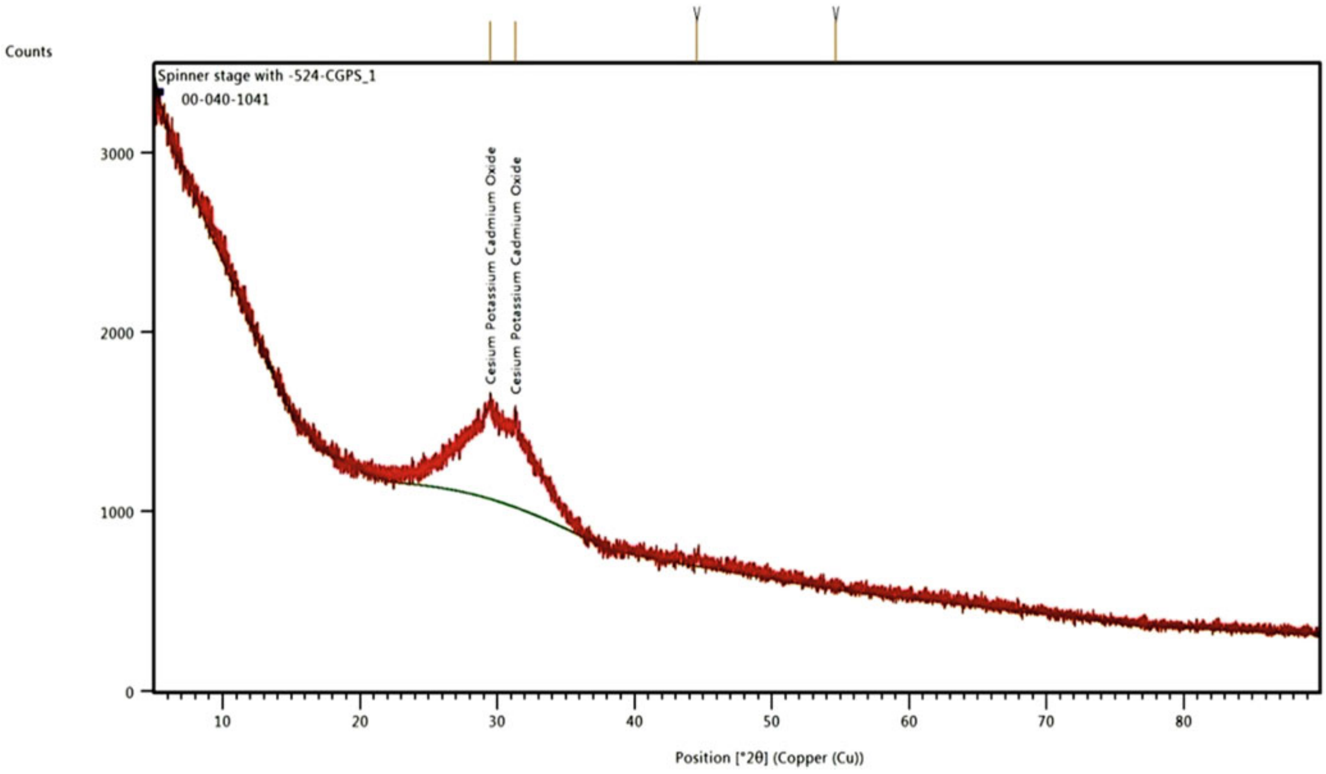

Fig. 1 XRD test on GGBS

by 40% and fly ash, GGBS replaced with cement by 10, 20, 30, 40, and 50%. By using these combinations, around 12 mixes were prepared and which is displayed in Table 1.

To prepare the fiber-reinforced concrete and cement, the silica fume by 40% and fly ash by 30% have been added together with cement to get the fly ash-based high-performance concrete. Along with that, PVA, PP, and glass have been added by 0.5, 1, 1.5, 2, and 2.5% concerning the cement weight. Similarly, instead of fly ash, GGBS has been used by 30% for the above category, so that a total of 30 different mixes were prepared for the above M40 grade mix and displayed in Table 2.

2.2 Casting and Testing

For the standard M40 concrete, a laboratory base mixer machine is used to mix the concrete ingredients (Figs. 2, 3, 4 and 5). Fibers are added with cement mortar paste slowly to get mixed and scattered in the concrete eventually. All the specimens are well compacted using a table vibrator. The illustrations are demoulded after 24 h, then after those specimens have undergone 28 days of water curing.

2.3 Compressive Strength Test

The compression test over the cube specimens has been performed according to IS: 516–1959 specifications. The cube specimens of size 150 mm x 150 mm x 150 mm were used for this test after 28 days of curing. The test specimens were removed from their mold after 24 h from casting and submerged immediately in water under room temperature and kept there until taken out just before the test. A Compression Testing Machine (CTM) of capacity 2000 KN was used to carry out this test. The specimen was placed in the CTM, and the sample is tested until it fails. The concrete cube specimen under a compression load in CTM is shown in Fig. 6.

$$\text{Compressive strength of the cube} = \text{Applied Load/Surface Area (MPa)}$$

2.4 Split Tensile Strength Test

One of the roundabout techniques is to discover the rigidity of cement that is the part malleable test. The split rigidity test is done on the pressure testing machine (CTM) over the chamber (Fig. 7) example as per IS: 516 – 1959 specifications. The cylinder of 150 mm diameter and 300 mm height specimens are used. Split tensile strength formula used is given below in (Eq. 1)

Table 1 Different concrete mixes for the grade of M40

S.No	Specimen ID	Cement	Fly ash	Silica Fume	GGBS	Fine aggregate	Coarse aggregate		Water to cement ratio	Water	SP
							10 mm	20 mm			
High-performance concrete											
1	CC	415	–	–	–	710	540	650	0.4	166	1.2
2	HPC	415	–	166	–	710	540	650	0.4	166	1.2
Fly ash-based high-performance concrete											
1	FHPC1	373.5	41.5	166	–	710	540	650	0.4	149.4	1.2
2	FHPC2	332	83	166	–	710	540	650	0.4	132.8	1.2
3	FHPC3	290.5	124.5	166	–	710	540	650	0.4	116.2	1.2
4	FHPC4	249	166	166	–	710	540	650	0.4	99.6	1.2
5	FHPC5	207.5	207.5	166	–	710	540	650	0.4	83	1.2
GGBS-based high-performance concrete											
1	GHPC1	373.5	–	166	41.5	710	540	650	0.4	149.4	1.2
2	GHPC2	332	–	166	83	710	540	650	0.4	132.8	1.2
3	GHPC3	290.5	–	166	124.5	710	540	650	0.4	116.2	1.2
4	GHPC4	249	–	166	166	710	540	650	0.4	99.6	1.2
5	GHPC5	207.5	–	166	207.5	710	540	650	0.4	83	1.2

Table 2 Fly ash and GGBS-based mixes for the grade of M40 with fibers

S. No	Specimen ID	Cement	Fly ash	Silica Fume	GGBS	Fine aggregate	Coarse Aggregate		Water to cement ratio	Water	SP	PVA fiber	PP fiber	Glass fiber
							10 mm	20 mm						
Fly ash-based high-performance fiber reinforced concrete														
1	FHPC3$_{PVA0.5}$	415	124.5	166	–	710	540	650	0.4	166	1.2	0.5		
2	FHPC3$_{PVA1.0}$	415	124.5	166	–	710	540	650	0.4	166	1.2	1		
3	FHPC3$_{PVA1.5}$	415	124.5	166	–	710	540	650	0.4	166	1.2	1.5		
4	FHPC3$_{PVA2.0}$	415	124.5	166	–	710	540	650	0.4	166	1.2	2		
5	FHPC3$_{PVA2.5}$	415	124.5	166	–	710	540	650	0.4	166	1.2	2.5		
6	FHPC3$_{PP0.5}$	415	124.5	166	–	710	540	650	0.4	166	1.2		0.5	
7	FHPC3$_{PP1.0}$	415	124.5	166	–	710	540	650	0.4	166	1.2		1	
8	FHPC3$_{PP1.5}$	415	124.5	166	–	710	540	650	0.4	166	1.2		1.5	
9	FHPC3$_{PP2.0}$	415	124.5	166	–	710	540	650	0.4	166	1.2		2	
10	FHPC3$_{PP2.5}$	415	124.5	166	–	710	540	650	0.4	166	1.2		2.5	
11	FHPC3$_{G0.5}$	415	124.5	166	–	710	540	650	0.4	166	1.2			0.5

Fig. 2 Conventional concrete cube specimens

Fig. 3 Conventional concrete cylinder specimens

$$\text{Split tensile strength} = \frac{2\text{P}}{\pi\,\text{dl}} \tag{1}$$

where

P = compressive load in kN.
l = length of the cylinder = 300 mm.
d = diameter of the cylinder = 150 mm.

Fig. 4 Specimen for pull out test

Fig. 5 Cube specimens in curing

Fig. 6 Compression test—cube specimen

Fig. 7 Split tensile test—cylinder specimen

2.5 Modulus of Rupture Test

The crystal example of size 100 mm × 100 mm × 500 mm is utilized to discover the modulus of a break on solidified cement following 28 days of restoring according to IS: 516–1959. The example is set in the flexure testing machine, and the burden is applied to the crystal's highest surface as a two-point stacking framework. The heap is used without stun and constantly expanded until the example fizzles. Figure 8 shows the flexural test arrangement on the solid crystal. The modulus of break is determined by utilizing the accompanying condition. The modulus of rupture formula used is given in Eq. 2.

$$\text{Modulus of rupture, } fb = \left(x\, d^2\right) / (P\, x\, l) \tag{2}$$

where P = maximum load applied to the specimen in kN
L = supported length = 500 mm
d = depth of the specimen = 100 mm
b = breath of the specimen = 100 mm.

Fig. 8 Modulus of rupture test—prism specimen

3 Result and Discussion

3.1 Compressive Strength Test

The test outcomes tracked down that the compressive strength of traditional solid (CC) and superior cement (HPC) were 42.3 MPa and 45.1 MPa, separately. The concrete is substituted by fly debris for 10%, 20%, 30%, 40%, and half, individually, and their particular compressive strength for fly debris-based superior cement, to be specific FHPC1, FHPC2, FHPC3, FHPC4, and FHPC5, are tried to be 43.5 MPa, 44.1 MPa, 45.5 MPa, 44.3 MPa, and 43.5 MPa, separately. On examining these outcomes, it is tracked down that 30% fly debris substitution (FHPC3) has the most extreme compressive strength contrasted with another level of fly debris substitution. The compressive strength of FHPC3 is 7.29% and 0.88% higher than CC and HPC concrete, separately. The test outcomes have appeared in Fig. 9.

Now, cement is replaced by GGBS for 10%, 20%, 30%, 40%, and 50%, respectively, and their compressive strength for GGBS high-performance concrete, namely, GHPC1, GHPC2, GHPC3, GHPC4, and GHPC5 are found to be 42.2 MPa, 44.1 MPa, 45.2 MPa, 44 MPa, and 43.2 MPa, respectively. On analyzing these results, it is found that 30% GGBS replacement (GHPC3) has maximum compressive strength compared with another percentage of GGBS replacement. The compressive strength of GHPC3 is 6.63% and 0.22% higher than CC and HPC concrete, respectively. The test results are shown in Fig. 10.

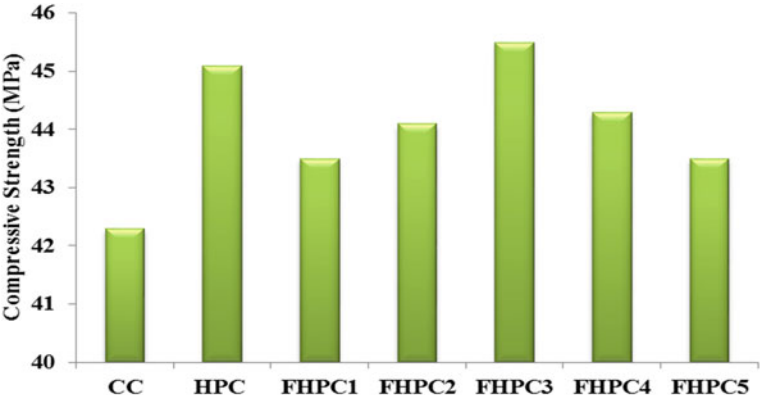

Fig. 9 Compressive strength of fly ash-based high-performance concrete

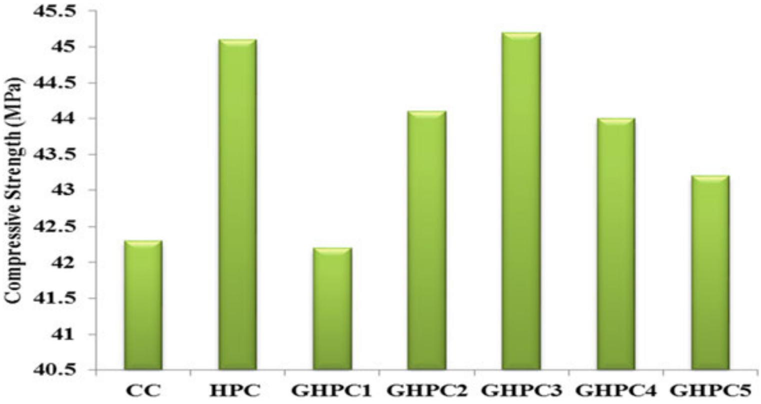

Fig. 10 Compressive strength of GGBS-based high-performance concrete

3.2 *Split Tensile Strength Test*

The test results found that the split tensile strength of conventional concrete (CC) and high-performance concrete (HPC) was 3.34 MPa and 3.56 MPa, respectively. The cement is replaced by fly ash for 10%, 20%, 30%, 40%, and 50%, respectively, and their respective split tensile strength for fly ash-based high-performance concrete, namely FHPC1, FHPC2, FHPC3, FHPC4, and FHPC5, was tested to be 3.44 MPa, 3.48 MPa, 3.59 MPa, 3.50 MPa, and 3.44 MPa, respectively. On analyzing these results, it is found that 30% fly ash replacement (FHPC3) has maximum split tensile strength compared with other percentages of fly ash replacement. The split tensile strength of FHPC3 is 7.22% and 0.84% higher than CC and HPC concrete, respectively. The test results are shown in Fig. 11.

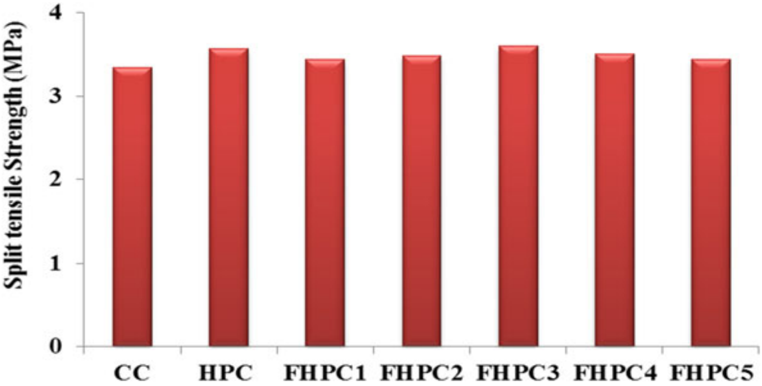

Fig. 11 Split tensile strength of fly ash-based high-performance concrete

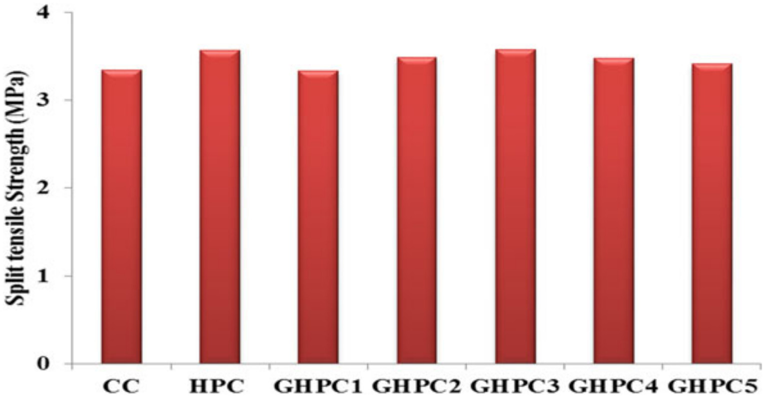

Fig. 12 Split tensile strength of GGBS-based high-performance concrete

Now, cement is replaced by GGBS for 10%, 20%, 30%, 40%, and 50%, respectively, and their split tensile strength for GGBS high-performance concrete, namely, GHPC1, GHPC2, GHPC3, GHPC4, and GHPC5 is found to be 3.33 MPa, 3.48 MPa, 3.57 MPa, 3.48 MPa, and 3.57 MPa, respectively. On analyzing these results, it is found that 30% GGBS replacement (GHPC3) has maximum split tensile strength compared with another percentage of GGBS replacement. The split tensile strength of GHPC3 is 6.66% and 0.28% higher than CC and HPC concrete, respectively. The test results are shown in Fig. 12.

3.3 Modulus of Rupture Test

The test outcomes tracked down that the modulus of the crack of customary solid (CC) and special cement (HPC) was 4.35 MPa and 4.63 MPa. The concrete is substituted by fly debris for 10%, 20%, 30%, 40%, and half, individually, and their different modulus of burst for fly debris-based superior cement, in particular, FHPC1, FHPC2, FHPC3, FHPC4, and FHPC5 are tried to be 4.62 MPa, 4.65 MPa, 4.72 MPa, 4.66 MPa, and 4.62 MPa, individually. It is tracked down that 30% fly debris substitution (FHPC3) has the greatest modulus of burst contrasted with another level of fly debris substitution on examining these outcomes. The modulus of FHPC3 is 8.16% and 1.93% higher than CC and HPC concrete, individually. The test outcomes have appeared in Fig. 13.

Now, cement is replaced by GGBS for 10%, 20%, 30%, 40%, and 50%, respectively, and their modulus of rupture for GGBS high-performance concrete, namely GHPC1, GHPC2, GHPC3, GHPC4, and GHPC5 is found to be 4.55 MPa, 4.65 MPa, 4.71 MPa, 4.64 MPa, and 4.60 MPa, respectively. On analyzing these results, it is found that 30% GGBS replacement (GHPC3) has a maximum modulus of rupture

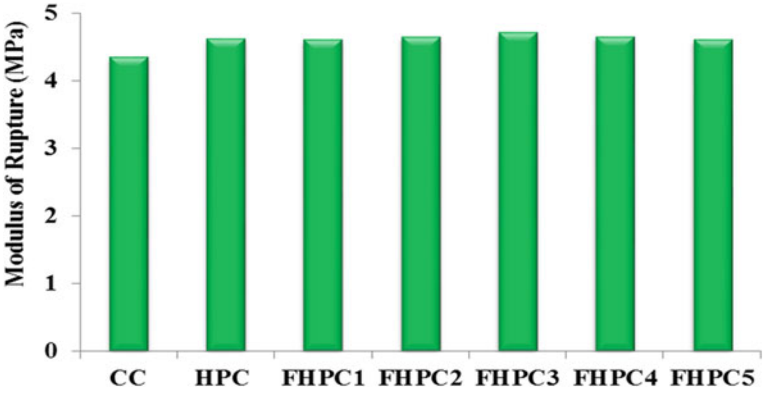

Fig. 13 Modulus of rupture of fly ash based high-performance concrete

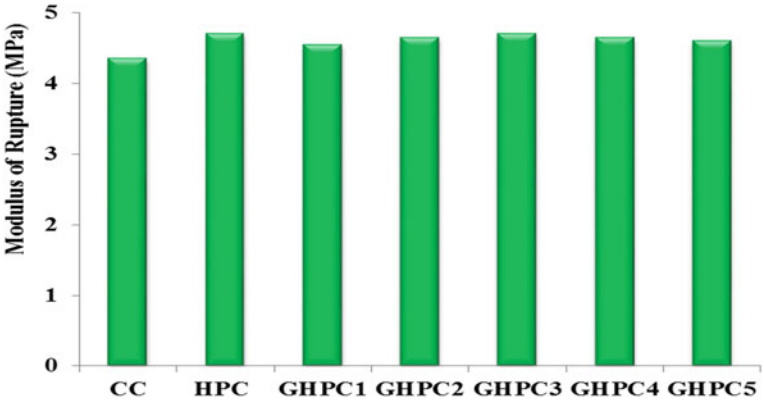

Fig. 14 Modulus of rupture of GGBS-based high-performance concrete

compared with another percentage of GGBS replacement. The modulus of rupture of GHPC3 is 7.95% and 1.71% higher than CC and HPC concrete, respectively. The test results are shown in Fig. 14.

4 Conclusion

Various tests have been conducted throughout the research work. In this research work, high-performance concrete, fly ash-based high-performance concrete, GGBS-based high-performance concrete, fly ash-based high-performance fiber-reinforced concrete and GGBS-based high-performance fiber-reinforced concrete in different proportions to study the mechanical properties, durability properties and structural performance of concrete.

The compressive strength of fly debris-based special cement (FHPC3) and fly debris-based elite fiber supported cement with mono fiber FHPC3G2.0, with mixture fiber (FHPC3) PVA0.5+G1.5 are discovered to be 7.29%, 10.1%, 8.16% higher than customary solid CC.

The split rigidity of fly debris-based special cement (FHPC3) and fly debris-based elite fiber-supported cement with monofiber FHPC3G2.0, with mixture fiber (FHPC3) PVA0.5+G1.5 are discovered to be 7.21%, 18.48%, 8.32% higher than traditional solid CC.

The modulus of a burst of fly debris-based superior cement (FHPC3) and fly residue-based elite fiber built up concrete with monofiber FHPC3G2.0, with half breed fiber (FHPC3) PVA0.5+G1.5, are discovered to be 8.16%, 13.01%, 14.7% higher than regular solidCC.

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