Performance evaluation of glass fiber reinforced high-performance concrete with silica fume and nano-silica

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Abstract. Investigators all around the globe are making unrivaled concrete by varying the proportions and admixtures. Fiber-reinforced concrete has various applications in structural components. Some of the fibers like glass, carbon, polypropylene, and aramid fibers give an improvement in generous properties like hardened, durability, stiffness, toughness, shrinkage. The purpose of this research is to investigate the properties of glass fiber reinforced high-performance concrete (GFRHC) for arriving high-performance trail mixes are prepared with cement replacement with silica fume (SF) ranging from 0% to 25%. An optimum mix is chosen in that constant 1.15 % cement is replicate with nano-silica. For that optimized mix along with nano-silica, glass fibers are induced at 1%, 2%, 3%, and 4% by weight of cement. 100x100x100mm cube moulds, cylinder moulds of 100x200mm, and beam moulds of 100x100x500 mm are prepared and cured for 7, 28 days then hardened strength are evaluated. The result shows that at 10% replacement of cement with silica fume at constant w/b ratio 0.31 shown 59.06 Mpa for Mix-3 and at 2% addition of glass fibers shows the 69.4Mpa, 9.57 Mpa, and 7.91 Mpa of compressive strength, split tensile strength, and modulus of rupture for Mix-8. The quality of concrete of all the mixes are is excellent at 2% addition of glass fiber UPV value is 5281m/s.

Keywords: Nano-Silica, Silica fume, Glass-fiber reinforced high-performance concrete, Compressive strength, flexural strength.

1. Introduction

Concrete is mostly frequently used material in construction sector due importance ans special concrete such as self compacting concrete[11-13] and glass fiber reinforced concrete[8-10,14-16] for different applications.A tiny number of short and randomly dispersed fibers, such as steel, glass, synthetic and natural, can overcome cement concrete's brittle failure properties. This type of concrete can be used in situations where concrete has a vulnerability, such as low durability or excessive shrinkage cracking. As a result of its low tensile strength, poor post cracking capability, and brittleness, as well as its large porosity, concrete is particularly sensitive to chemical and environmental assault. Worldwide building of more complex engineering structures has become a reality in recent years. Because of this, concrete must have high strength as well as a high degree of
workability. By adding different fibers and admixtures in varying amounts, researchers all around the world are creating high-performance concrete. A broad range of filaments, for example, aramid, polypropylene, glass, carbon, and polypropylene, improve cement properties like as stiffness and exhaustion blockage. As a result of its intriguing characteristics, fiber-supported cement offers a variety of applications in the structural design sector. The glass fibre Because of its low weight, reinforced concrete (GFRC) is a relative advancement in the significant innovation area. GFRC has both strong compressive and twisting strength[14-16]. Fiber-built-up concrete is a relatively new composite material in which the substantial is supported by short, consistently conveyed discrete strands (up to 35 mm long), enhancing many design properties such as flexural and shear qualities, as well as weakness, effect, and temperature and shrinkage breaks. Fibers of 25mm length and spray applications employ fibers up to 35mm in length. Renewed concrete comprises twisted steel bars or high tension wires that are woven into a continuous pattern. High-tension wires for prestressing technology using glass reinforcing have helped overcome concrete’s inability to withstand the strain; nonetheless, concrete's compressive strength is excellent. High rigidity (2-4 GPa) and youns modulus (70-80 GPa) of glass fiber, strain properties (2.5-4.8 percent stretching at break), and a negligible owner at encompassing temperature are large elements of glass fiber. This material has a measurement of somewhere in the range of 0.005 and 0.15 millimeters. 1.3 mm is the measurement of the groups.ZhuYuan and Yanmin Jia (2020) [1], the study of the impact of glass fibre (GF) and polypropylene fibre (PPF) on the mechanical and microstructural properties of concrete as a function of water/binder ratio and fibre concentration During the experiment, the concrete samples were produced with varied water/binder ratios (0.30 and 0.35), GF and PPF concentrations (0.45, 0.90, and 1.35 percent by volume fractions), and curing times (7 and 28 days). The effect of GF on water absorption was much greater than that of PPF. When the water-binder ratio was 0.30.Barham

H.Mohammed et.al (2020) [2], A total of fourteen blends, UHPFRC's mechanical attributes, and pliability were assessed, and it was found that a lower w/b in better mechanical execution. Besides, the blends containing 1.5 to 3 percent MGF displayed the most noteworthy compressive strength, coming to up to 160 MPa. Besides, the information showed that extra strength improvement above 1.5 percent MGF was impractical.PeiYa et.al (2021) [3]. It was found that both the kind and amount of additional fibers had an impact on fresh and hardened UHPC-FM concrete characteristics. Expanded fiber focus brought about a diminishing in the progression of new UHPC-FM blends, with PPF-containing glues showing the greatest smoothness. Compressive strength (CS) was likewise upgraded with the expansion of 0.5 percent and straightly diminished with the expansion of more noteworthy amounts. The flexural strength of tests containing 2.5 percent BF, PPF, and GF expanded by 20.8 percent, 26.9 percent, and 27.9 percent, separately, contrasted with the control example (UHPC-A0) 25.8 percent flexural strength improvement for PPF samples and 27.9 percent increase for composites with 25.8% glass fibers (GF). A rise of 20.04 percent occurred in BF, 24.92 percent occurred in the case of PPF, and 26.05 percent occurred in the case of GF, as opposed to the reference sample (8429.5-kN). It was shown that UHPC-FM samples made from BF/PPF/and GF were tougher than control specimens by an average of 4.64, 4.75, and 4.86 times each, respectively. Habil Ahmad et.al (2021)[4], properties of fiberglass-polymer reinforced solid concrete (GFRP) samples were investigated. However, with the same amount of reinforcement, glass fiber reinforced polypropylene fiber bars showed 2% higher maximum strength and 19% higher plasticity than similar fiber concrete samples with the same amount of reinforcement but without glass fiber reinforcement (GFRP–HC–NFC). Gokhan Calisa et.al (2021) [5] enhances compressive strength and thermal conductivity when GCC is used. Aside from that, the addition of GF to a concrete mix increases its flexibility. Arun Kumar and Parashar Ankur Gupta (2021) [6], The workability of the combination decreased as the amount of bagasse ash in the mix increased. If the concrete is produced with 10% bagasse ash, the optimal percentage of steel fibres and glass fibres is 1% and 1.5 percent, respectively. Z.Xiong et.al.(2021) [7], To minimise steel corrosion, fibre polymeric bars (FRP) have been utilised as reinforcement in saltwater concrete (SSSC). The use of glass fibre and/or wax substance substantially strengthens the connection and improves the R-FRP rod's strength. In general, fibrous fibres have a synergistic impact with fuel and anti-inflammatory compounds, although the
connection stays strong owing to the early breakdown of FRP columns. Finally, the fundamental model is intended to anticipate the SSSC-mandated behaviour of FRP bars. Hanuma Kasagani et.al (2021)[10] analyzes the blend of four unique lengths of glass strands that were mixed in a reviewed glass fiber. The uniaxial pressure and pressure conduct of M50 grade concrete with evaluated glass filaments at three distinct volume portions – that is, 0.3, 0.4 and 0.5% -for five unique fiber volume mixes were contemplated. It was seen that adding SGGF to the substantial outcomes in higher pinnacle strength and adding LGGF to the substantial brought about higher post-peak deformation. S. R. R. Teja Prathipati et.al (2020)[14], analyzes the mix of four distinct lengths of glass strands consolidated in a tried glass fiber. The uniaxial strain and tension lead of M50 grade concrete with evaluated glass fibers at three separate volume parts – 0.3, 0.4, and 0.5 percent – were considered for five unique fiber volume blends. It was found that adding SGGF to the generous outcomes in expanded apex strength and that adding LGGF to the significant outcomes in expanded post-top deformity. Hanuma Kasagani and C. B. K. Rao (2018) [15]. This job is done using a tiny 3 mm fibreglass with a concrete (M30) strength ranging from 0.1 to 0.5 percent at flat and smooth pressure. Under stress and pressure, stressing out is a stressful habit. Because the wire's performance is effectively standardised at the level of fibre dispersion and breakage, the greater the fibre dispersion coefficient and the fibre dispersion coefficient, the higher the composite strength.

2. Methodology

Glass fiber reinforced high-performance concrete (GFRHC) addition to the realm of concrete manufacturing. The benefits of glass fibers are their small in weight, strong compressive strength, and flexural strength. The purpose of this research is to investigate the properties of glass fiber reinforced high-performance concrete (GFRHC), for arriving high-performance concrete trail mixes are prepared with cement replacement with silica fume (SF) ranging from 0% to 25%. An optimum mix is obtained in that constant 1.15 % cement is replicate with nano-silica. For that optimized mix along with nano-silica, glass fibers are induced at 1%, 2%, 3%, and 4% by weight of cement. 100x100x100mm cube moulds, cylinder moulds of 100x200mm, and beam moulds of 100x100x500 mm are prepared and cured for 7, 28 days then hardened and quality properties are evaluated.

3. Materials and mix proportions

OPC-53 grade cement from the KCP brand is selected for experimental work conforming to IS 12269:1987 [20]. It is having a specific gravity of 3.15. Fly ash is collected locally at VTPC, Vijayawada. Specific gravity of 1.9. The size of fine aggregate is limited to a maximum of 4.75 mm gauge is referred to as natural sand beyond is a coarse aggregate. The considered sand was zone-III grade and having a specific gravity of 2.3 respectively as per IS 383-1970 [21], [22]. In my experimental study 12.6mm and 20mm, coarse aggregates are considered in the ratio of 30:70 were used, and it having a specific gravity of 2.85. Silica fume having a specific gravity of 2.20, the texture is smooth and looks light to dark grey. Nano silica having a specific surface area of 202 m²/g, specific gravity is 2.3, the total SiO₂ content is 99.88% purity having a particle size of 17 nano. Glass fiber of 24 mm length is used for the study procured from “Jogani industry”. The chemical admixture “Master Glenium- sky8630” is used as a Superplasticizer as per IS 9103:1999 [19] and constant w/b ratio. Fig.1 shows the view of materials used for the study. The study is conducted based on the availability of the material in that trail mixes are prepared with cement replacement as silica fume (SF) ranging from 0% to 25%, and suitable mix proportion is obtained out of 6 mixes based on strength properties as Mix -3. For that Mix-3 a constant percentage of 1.15 NS replicate with the weight of cement in that same mix glass fibers are induced at 1%, 2%, 3%, and 4 % by weight of cement. Then four mixes are prepared they are from Mix-7 to Mix-10. In all associated mixes, mix proportions are designed as per IS 10262:2019 [18]. The composition details of all the mixes are shown in Table 1.
4. Experimental study

4.1 Casting and curing of concrete

The materials are stored at room temperatures and the entire mould surface is completely oiled and free from dust and organic matter. The mixing of aggregates, binders, water, superplasticizers was mixed in a pan mixer with an overall time of 7-10 min (IS 12119:1987)[24]. The concrete sample is poured in the mould for each associated mix is vibrated and remove extra concrete and level. The moulds are kept open for up to 24 hrs and samples are placed into the curing tank for 7 days and 28 days as shown in Fig. 2 Casting and curing of samples.
4.2 Test methods

The following tests are conducted for each mix in UTM having a capacity of 100 tones in the laboratory. The compressive strength test and split tensile strength and flexure strength test were conducted following IS: 516-2004[17] at 7 and 28 days of curing and ultrasonic pulse velocity at direct test at 28 days of curing as per IS 13311 (Part1):1992[23]. All samples of each series were cured at 27±1°C. A ten mixes are proposed for the study in each mix, six cubes of 100x100x100mm were made to investigate the direct stress 7, 28 days of curing, three beam moulds of 100x100x500 mm prepared to know bending strength at 7, 28 days of curing, and 6 Cylinders of 100x 200mm are made to know the split tensile strength and hardened strength are to be evaluated. Fig.3 shows the view of the hardened test of concrete. For the cubes direct test of ultrasonic pulse velocity test were done for 28 days of curing.

![Image](a) A view of compression test  (b) A view of split tensile test  (c) A view of flexure test

Figure.3. Hardened test of concrete.

5. Results and Discussion

To investigate the mixes, cube samples are prepared and direct stress is obtained from the UTM testing machine. A plot of compressive strength as shown in Fig.4.a reveals that at 10 % replacement of cement with SF at constant w/b ratio 0.31 shown 59.06 Mpa (Mix-3) of optimum strength. For that Mix-3 at a constant amount of 1.5 % NS is replaced with cement by weight and glass fibers (GF) are added at 1% to 4 % by weight of cement in that at 2% of GF addition gives 69.4 Mpa than Mix-3. In addition to silica fume to control concrete mix, the strength increment is observed 20.5 %, 30.32 % at 5%, and 10 % SF as replacement of cement for 28 days with control mix -1. After increment in SF there is a slight decrement 1.59%, 1.58% and 2.47% at 15% SF, 20% SF and 25% SF as replacement of cement for 28 days with control mix -1. Based on results, Mix-3 is chosen for that addition of GF in Mix-3 along with a constant amount of 1.15% NS. The propose mixes gives strength increment of 35.41 % for Mix-7, 53.12% for Mix-8, 43.66% for Mix-9 and 41.21 % for Mix-10 than control concrete Mix-1 at 28 days of curing. It’s due to the addition of NS leads to the formation of C-S-H gel leads to strength the ITZ zone at the same time by the addition of GF the particles are combined and increase in the strength. The harden properties of GFRHC are listed in Table 2.

Fig.4.b. Shows the split tensile strength of concrete at 7 and 28 days of curing. In that plot split tensile strength is shown maximum gain is from 5 % to 20% SF and same strength is increased due to GF induction from 1% to 4% by weight of cement in respective mixes. It observed that maximum split tensile strength is at Mix-8 from all the mixes. In addition of SF to control concrete mix the strength increment is observed 0.262 %, 1.10 %, 4.413 % 7.048% for replacements of 5%,
10%, 15% and 20% SF as replacement of cement for 28 days. After increment in SF, there is a more decrement at 23.17 at 25% SF as replacement of cement for 28 days with control mix -1. It’s due to not formation C-S-H gel or weak zone. Based on the results, optimization Mix-3 is chosen for that addition of GF along with a constant amount of 1.15% NS. The mixes shown the strength increment of split strength about 15.80%, 32%, 14.2%, and 9.24% for Mix-7 to Mix-10 with comparing the control Mix-1. Glass fibers having good tensile properties leads to increases in the split strength in all the GF mixes for 28 days of curing.

Table 2. Hardened properties of GFRHC mix

| Mixes Designations | Hardened Tests          | 7 Days | 28 Days | 7 Days | 28 Days | 28 Days | 28 Days | 28 Days | 28 Days |
|--------------------|-------------------------|--------|---------|--------|---------|---------|---------|---------|---------|
| Mix-Type           | Mix Id                  |        |         |        |         |         |         |         |         |
| 0-SF (CC)          | Mix-1                   | 36.88  | 45.321  | 6.29   | 7.25    | 5.896   | 5157    |         |         |
| 5-SF               | Mix-2                   | 39.01  | 54.655  | 6.24   | 7.269   | 6.72    | 5157    |         |         |
| 10-SF              | Mix-3                   | 39.04  | 59.06   | 6.44   | 7.33    | 6.82    | 5251    |         |         |
| 15-SF              | Mix-4                   | 29.58  | 44.6    | 7.08   | 7.57    | 6.71    | 5105    |         |         |
| 20-SF              | Mix-5                   | 29.1   | 44.5    | 6.02   | 7.761   | 7.05    | 5013    |         |         |
| 25-SF              | Mix-6                   | 28     | 44.22   | 7.19   | 5.57    | 7.106   | 4739    |         |         |
| 10%SF+1.5% NS+1%GF | Mix-7                   | 41.8   | 61.37   | 5.3    | 8.396   | 7.771   | 5208    |         |         |
| 10%SF+1.5% NS+2%GF | Mix-8                   | 46.11  | 69.4    | 6.5    | 9.57    | 7.91    | 5281    |         |         |
| 10%SF+1.5% NS+3%GF | Mix-9                   | 42.5   | 65.12   | 5.1    | 8.28    | 7.748   | 5208    |         |         |
| 10%SF+1.5% NS+4%GF | Mix-10                  | 40.6   | 64      | 4.9    | 7.92    | 7.63    | 5076    |         |         |

Fig.4.c. Bending strength of concrete at 28 days of curing. In addition, silica fume (SF) and glass fibers (GF) show good co-relation in GFRHC mixes. In all the GFRHC mixes, the bending strength is increasing by the addition of silica fume and glass fibers. It is shown that the maximum bending strength is observed is 6.72 Mpa, 6.82 Mpa, 6.71 Mpa, 7.05 Mpa, 7.1 Mpa and 7.106 Mpa for all the silica fume addition leads at the same time glass fiber addition also leads to an increase in the bending strength reported as 7.71 Mpa, 7.91 Mpa, 7.748 Mpa and 7.63 Mpa. It observed that maximum modulus of rupture is observed at Mix-8 from all the mixes. In addition of SF to control concrete mix the strength increment is observed 13.9%, 15.67%, 13.80%, 47.55% and 20.522% for replacements of 5%, 10%, 15%, 20% and 25% SF as replacement of cement for 28 days. From results, Mix-3 is chosen for that addition of GF along with a constant amount of 1.15% NS. Glass fibers having good tensile properties leads to increases in the strength in all the GF mixes for 28 days of curing it observed that 31.80%, 34.15%, 31.411% and 29.4% increment for Mix-7 to Mix-10 with comparing the control mix-1.

Fig.4.d shows the ultrasonic pulse velocity of concrete at 28 days of curing. The Ultrasonic pulse velocity test is performed on concrete to assess the quality of concrete by passing ultrasonic pulse velocity through it as per IS: 13311 (Part 1) – 1992[23]. It is shown that by direct test all the GFRHC mixes the pulse velocity propagated gives better results. The quality of concrete of GFRHC mixes is excellent due to above 4500 m/s velocity. All the mixes show good quality of concrete due to density, homogeneity, and uniformity, it comparatively obtains higher velocity in concrete.
6. Conclusion

As a result of its low tensile strength, poor post cracking capability, and brittleness, as well as its large porosity, concrete is particularly sensitive to chemical and environmental assault. In the new materials, which have special properties that make them extremely adaptable to any environment, the aforesaid shortcomings of plain concrete are solved. Fiber A relatively new composite material, reinforced concrete is one of them. As a result, silica fume (GF) is added to the normal mix to preserve sustainability.

Following observations and experimental results GFRHC mixes are made:

1. Ten mixes are prepared to assess the strength properties reveals that at 10% replacement of cement with SF at constant w/b ratio 0.31 shown 59.06 Mpa.
2. The 2% addition of GF shows the 69.4 Mpa in Mix-8. In all the GFRHC mixes strength increment is observed at 20.5 %, 30.32 % at 5% and 10% SF as replacement of cement and addition of GF strength increment about 35.41 % for Mix-7, 53.12% for Mix-8, 43.66% for Mix-9 and 41.21 % for Mix-10 than control concrete Mix-1 at 28 days of curing. It’s due to the addition of NS leads to the formation of C-S-H gel leads to strength the ITZ zone at the same time by the addition of GF the particles are combined and increase in strength. In
addition to SF, there is a slight decrement but it's nominal about 1.59%, 1.58%, and 2.47% at 15% SF, 20% SF and 25% SF as replacement of cement for 28 days with control mix-1.

3. The split tensile strength is shown in Fig.4b the maximum gain is from 5% to 20% SF and GF induction from 1% to 4% by weight of cement mixes. It observed that maximum split tensile strength is at Mix-8 from all the mixes.

4. In addition of SF to control concrete mix the strength increment is observed 0.262 %, 1.10 %, 4.413%,-7.048% for replacements of 5%, 10%, 15% and 20% SF as replacement of cement and increment of 15.80%, 32%, 14.2 % and 9.24 % for Mix-7 to Mix-10 due to GF addition with comparing the control mix-1 for 28 days curing. The strength increment is due to the formation of C-S-H gel from SF and NS but due to addition of GF leads to increases in the split strength in all the GF mixes for 28 days of curing.

5. It is shown that decrement at 23.17 at 25% SF as replacement of cement for 28 days with control mix -1. It is due to not formation C-S-H gel or weak zone. The mixes showed the strength increment of split strength about. Glass fibers having good tensile properties lead to increases in the split strength in all the GF mixes for 28 days of curing.

6. It is shown that the maximum bending strength is observed is 6.72 Mpa, 6.82 Mpa, 6.71 Mpa, 7.05 Mpa, 7.1Mpa, and 7.106 Mpa for all the silica fume addition and GF leads to an increase in the bending strength reported as 7.71Mpa, 7.91Mpa, 7.748 Mpa and 7.63 Mpa. It observed that maximum modulus of rupture is observed at Mix-8 from all the mixes.

7. In Ultrasonic pulse velocity, direct tests are done for all the GFRHC mixes, the pulse velocity propagated gives better results. The quality of concrete of GFRHC mixes is excellent due to above 4500m/s velocity as shown in Fig.4d. All the mixes show good quality of concrete due to density, homogeneity, and uniformity, it comparatively obtains higher velocity in concrete.

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