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Experimental Study of Glass Fiber Reinforced Concrete Incorporating Micro Silica

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The most common building material utilized worldwide is concrete. Concrete with higher compressive strength is becoming more and more in demand as the trend toward using it more widely for high rise buildings. Experimental study of glass fiber (GF) reinforced concrete incorporating micro silica was investigated in this study. The concrete is prepared by using M40 mix. GF with 12 mm length with aspect ratio of 857 is used. Four volume fractions of 0%, 0.4%, 0.8% and 1.2% by weight of cement and micro silica with 5% by weight of cement are used. The fiber is distributed randomly in all directions. The mixes were cast and tested for workability, compressive strength, flexural strength, water permeability test, drop weight Impact test, bond strength test and residual compressive strength at elevated temperature. Micro structural study is done with SEM analysis. Workability of glass fiber reinforced concrete decreased with increase in GF. Compressive strength show 12% increment whereas Flexure strength is increases 35% compare to normal concrete. Different percentages of glass fibres and micro silica have lower water penetration depths. With regard to the fire resistance test the compressive strength at

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elevated temperature decreases significantly. Impact resistance and bond strength of glass fiber reinforced concrete with micro silica increases with increase in fiber content. Hence, it's suggested to use glass fiber in the concrete according to use of concrete.

Keywords: Glass fibers; glass fiber reinforced concrete; micro silica; elevated temperature.

1. INTRODUCTION

The most common building material utilized worldwide is concrete. Small and uneven fibres are uniformly placed in a unique type of concrete called fibre reinforced concrete (FRC). Concrete with higher compressive strength is becoming more and more in demand as the trend toward using it more widely for high rise buildings. Therefore, micro silica is added to achieve that. Micro silica is an amorphous (non-crystalline) form of silicon dioxide, often known as silica fume. Utilizing micro silica has several benefits, including a reduction in thermal cracking brought on by the heat of cement hydration and an increase in resistance to attack by sulphate and acidic fluids. Experimental studies of glass fiber reinforced concrete incorporating micro silica were investigated in this study. The concrete is prepared by using M40 grade, GF with 18 mm length and four volume fractions of 0%, 0.4%, 0.8% and 1.2% by weight of cement are used. The mixes were cast and tested for compressive strength, flexural strengths, water permeability test, drop weight impact test, and SEM analysis. It's set up out that plasticity of concrete is reduced by enhancing the volume of glass fiber. There's the improvement in the strength in the concrete. Hence, it's suggested to use glass fiber in the concrete according to use of concrete.

2. GLASS FIBER REINFORCED CONCRETE (GFRC)

Compared to other cementitious composition, Glass fibre reinforced concrete offers greater resilience to alkaline conditions. Concrete that has been reinforced with individual glass fibres of various lengths and sizes is known as glass fibre reinforced concrete. Glass strands are typically employed in veneer plates, outside claddings, and other components when their construction-related strengthening effects are required. The use of water-reducing admixtures is necessary because GFRC is stiff in its fresh condition and has less slump, making it less workable. Extrusion, injection, and spraying procedures are only a few options for doing this. Also discovered to have a remarkable influence on the GFRC was the type of cement. The characteristics of GFRC are also influenced by the fibre length, sand and filler type.

3. LITERATURE REVIEW

Chawla et al. studied on the glass fiber reinforced concrete composites. In this experimental work it was found that modulus of elasticity of glass fiber reinforced concrete was increased 4.15% compared with control mix. When adding glass fibers by 0%, 0.33%, 0.67%, 1% respectively, mechanical properties like compressive strength, flexure strength, after 28 days increases 5.19% and 37% respectively [1].

Karein et al. investigated how adding micro silica to concrete as a partial replacement affected its physical characteristics. Micro silica's influence on mechanical and durability qualities were investigated. Concrete is more durable and uses less cement because of micro silica. The outcome demonstrated that using micro silica resulted in improvements in strength, durability, and surface electric resistance as well as a reduction in permeability. The reported and maximum depth of the water absorption examination at 28 and 90 days contributed to a decrease in the use of micro silica. According to the compressive strength test, replacing 7.5% of the cement with micro-silica results in a 20% increase in the concrete's compressive strength [2].

Deshmukh et al. conducted a study to determine the effects of glass fibres on ordinary portland cement concrete. Through the use of compressive strength tests, flexural strength tests, and splitting tensile strength tests, the effect of adding glass fibres to concrete at various percentages between 0% and 0.1% has been examined in this research. In this study OPC of 53 grade is used and glass fibers of 12 mm in length are used. The glass fibers of 0%, 0.3%, 0.6% and 1.0 % by volume fraction of concrete were used. In comparison to standard M20 concrete, it was found that adding 1% of glass fibre improved 28-day compressive strength by 7.5%. Concern with percentage of addition of glass fibers are gives better results by addition 1%. In comparison to regular M-20 concrete, the 28-day flexural strength is raised by 24.5% with the inclusion of 1% glass fibre. After 28 days in comparison to standard M20 concrete, adding 1% of glass fibre increases splitting tensile strength by 37.4% [3].

Dehgan et al*.* examined the recycled glass fiber reinforced polymer additions to portland cement concrete. In the study, the decreased workability was fixed by preconditioning the recycled GFRP to an SSD (saturated surface dry) condition. Drying shrinkage was not improved by the addition of recycled GFRP or glass fibers as compared to the control concrete [4].

Leo et al. studied how micro silica affected the clean characteristics of concrete's mortar phase. Various fresh concrete checks, including workability, flow ability, and cohesiveness with varying cement, water, and micro silica contents, have been completed. The effect of the micro silica addition increased cohesiveness, which in turn decreased segregation. Concrete became more viscous due to micro-silica. The workability is reduced when micro silica is added. Slump and flow spread were both reduced when micro-silica content increased [5].

George et al. investing in the future studies on concrete reinforced with glass fibre. As partial cement relief to cement in concrete blend, glass filaments were used at varied dosages of 0.5%, 1.0%, and 1.5% of cement content (by weight). M40 concrete with a w/c rate of 0.4 was the grade used in the discussion. The impact of various glass filament dosages on the cohesive strength of steel and concrete in confirmed concrete was investigated. The samples were subjected to harsh terrain for 60 and 90 days. The plasticity decreased as the fibre lozenge dosage increased, and 1.5% fibre dosage had the lowest slump value. The compressive strength of concrete reinforced with glass fibres was remarkably unaffected by the addition of glass filaments. With regard to the exposure investigations, 1.0% fibre dosage of glass fibre reinforced concrete showed improved compressive strength and ultimate bond strength retention in comparison to 0.5 and 1.5% fibre dosage [6].

Shen et al. used fly ash, limestone powder, and micro-silica as partial cement replacements when researching the mechanical properties of concrete. When micro silica was used as the partial replacement for cement, the best mechanical qualities were seen. The outcome shows that the application of micro-silica resulted in an improvement in strength, durability, and surface electrical resistance as well as a decrease in permeability. The least resistant to freezing was seen in the micro silica. Micro silica-infused concrete displayed higher crack resistance [7].

Hilles et al. studied the mechanical behavior of glass fiber-reinforced high strength concrete. This study examined the effects of varying contents of alkali resistant glass fibre (AR GF) on the mechanical behavior of high strength concrete (HSC). A variety of AR-GF contents, typically 0.3%, 0.6%, 0.9%, and 1.2% by weight of cement, were used to make concrete fusions. According to ASTM standards, the mixtures were cast and tested for compressive, tensile, and flexural strengths. When the dosage of the fibre increased from 0.0% to 1.2% independently, the compressive strength increased from 57.85 to 66.6 MPa, the splitting tensile strength increased from 3.06 to 4.92 MPa, and the flexural strength increased from 4.84 to 7.27 MPa.. With a 1.2% fibre content, the splitting tensile strength of HSC rose by 63.22% over time. Flexural strength progressively increased with 1.2% strands, reaching a 52.36% increase [8].

Nili et al. investigate the strength properties, they added nano-silica (nS) from 0%, 0.5%, 3%, 5%, and 7.5% and micro-silica (mS) from 0%, 5%, and 7.5% by weight of cement in concrete and cement paste. By adding nS to cement paste and concrete mixture, compressive strength of both concrete and cement paste is considerably increased. The nS-3% sample exhibits the maximum compressive strength. When compared to concrete, cement pastes' rate of strength growth is accelerated by the presence of micro-silica. The strength of paste of nano-silica rises with micro-silica incorporation at 7, 28, and 91 days. For the concrete sample nS5-mS5, the simultaneous inclusion of nano-silica and micro-silica increases the strength of cement paste and concrete [9].

Ali et al. studied how the cost and environmental impact of concrete pavement were affected by the flexural behaviour of glass fibre reinforced recycled aggregate concrete. This study calculated the critical mechanical characteristics (elastic modulus, flexural strength, and residual strength) of concrete mixes including various proportions of GF (as 0%, 0.25%, 0.5%, and 1% volume fraction) and concrete waste aggregate CWA (as 0%, 30%, 50%, and 100% substitution of natural coarse aggregate). Concrete's compressive strength, elastic modulus, and flexural strength advance to their maximum levels at 0.25% to 0.5% GF lozenge for all CWA (30%, 50%, and 100%) conditions [10].

Kumar et al. studied on high-performance glass fibre reinforced concrete was conducted. It deals with the qualities of freshly produced concrete as well as strengthened concrete that take on research into the usage of glass fibres with beams, cubes, and other structural elements. The concrete grade of M20 has been utilized for strength and durability, with varying amounts of glass fibre ranging from 0 to 1% by mass. The test was carried out after the specimen had been cast for 7 and 28 days. Use 0.33%, 0.67%, and 1.0% of glass fibre in concrete for M20 grade. When compared to the control mix, it was discovered that the compressive strength of concrete for 7 and 28 days was moderately increased. By incorporating 0.33% glass fibre into concrete, the compressive strength of M20 with glass fibre for 7 days and 28 days is 19.23 N/mm2 and 41.32 N/mm2, respectively. Flexural strength of M20 with 1% Glass fibre has been successfully accomplished and gradually increased over 7 days and 28 days to 14.5 N/mm2 and 18.8 N/mm2, respectively [11].

Tassew et al. carried out the study of mechanical properties of glass fiber reinforced ceramic concrete on fresh and hardened properties with fiber content percentages ranges from 0% to 2% were examined that addition of glass fibers to a ceramic concrete mix reduced the flow of the concrete. Depending on the fibre length or mix composition, the flexural strength of ceramic concrete improved as the volume fraction of glass fibre was rising. The flexural strengths of glass fiber reinforced ceramic concrete was increased by 30%. The compressive strength shows about 12% increments when 2% glass fibres were added. The direct shear strength of ceramic concrete increases with increase in the glass fiber percentage irrespective of the mix composition [12].

4. METHODOLOGY

4.1 Mixcomposition

Concrete samples with constant amount cement content, coarse aggregate, glass fibers, fine aggregate were made and specimens were cast. 28 days curing is done for specimens and maximum 28 days strength achieved was 56.88MPa. To find out optimum content of micro-silica without compromising the strength different attempts were made. During the mix proportioning of different mixes, the cement content was varied with micro-silica in proportion 0%, 5%MS, 5%MS+0.4%GF, 5%MS +0.8%GF, and 5%MS +1.2%GF respectively at water cement ratio of 0.36. Then its fresh properties, mechanical properties and durability properties were evaluated and compared with that of control mix.

4.2 Physical Properties of Glass Fibers

The physical properties of glass fiber used in this investigation were shown in Table 2.

Table 1. Mix proportion to be cast

S. no.	Cement	Addition of glass fibers to concrete (%)	Addition of micro silica to concrete (%)
1	Ordinary Portland cement	0%	0%
2	Ordinary Portland cement	0%	5%
3	Ordinary Portland cement	0.4%	5%
4	Ordinary Portland cement	0.8%	5%
5	Ordinary Portland cement	1.2%	5%

Table 2. Physical properties of glass fibers

S. No.	Physical property	Result
1	Fiber length	12-18mm
2	Specific gravity	2.68
3	Aspect ratio	857
4	Water uptake	<0.1%
5	Tensile strength	3500MPa

Table 3. Properties of micro silica

S. No.	Parameter	Unit	QC limit	Test Result
1	Appearance	-	Free flowing powder	Pass
2	Color	-	White	Pass
3	Dry bulk density	Kg/m3	500-700	650
4	Moisture content	%	0.1-0.35	0.19
5	Particle size	Microns	0.03-0.1	0.07
6	Sio2	%	>85	86.4

4.3 Physical Properties of Micro Silica

Micro silica is composed of silicon dioxide (SiO_2) obtained from silicon metal and ferrosilicon. Micro silica reacts with calcium hydroxide in cement to form more calcium silicate hydrates increasing the strength of concrete. Properties of micro silica are shown in Table 3.

5. RESULTS AND DISCUSSION

5.1 Workability

The slump test of the glass fiber reinforced concrete was carried out to find out the workability property of glass fiber concrete mix admixed with micro-silica. The Concrete Slump Test or Slump Cone Test is used to determine the workability or consistency of concrete mixes made in the laboratory or in the field as work progresses. The results are shown in Fig. 1.

Fig. 1 represent the slump value of control and glass fiber concrete utilizing micro-silica in cement. From the figure it was seen that the value of slump is going on decreasing side from 51 mm to 49.5 mm when micro silica is added into it. After adding glass fibers and micro silica both in the concrete it also decreased from 49.5 mm to 40 mm. The workability of glass fiber reinforced concrete decreased significantly with increasing fiber content as shown in the figure. The decrease in slump with increasing glass fiber content is likely due to the fact that the fiber geometry prevents aggregates from slipping through adjacent aggregates unimpeded [13,14].

5.2 Compressive Strength

To determine the mechanical characteristics of concrete mixes admixed with micro-silica as a partial replacement of cement at varied percentages, a compressive strength test of glass fibre reinforced concrete containing micro silica was conducted. In Fig. 2, the results are displayed.

After 7 days of curing age the compressive strength of concrete noted as 31.24MPa, 33.45MPa, 34.08MPa, 34.75MPa and 34.788MPa are respectively at 0%, 5%MS, 5%MS+0.4%GF, 5%MS +0.8%GF, and 5%MS +1.2%GF. Concrete's compressive strength of 7 days age cubes containing micro silica and glass fiber was increased by 6.60%, 1.84%, 1.92%, and 0.11% which shows that adding of micro silica to concrete mix can increase the compressive strength of concrete over controlled concrete, Due to their high reactivity, micro-silica particles accelerate the hydration of C_3S when they are added [7,8]. But by adding glass fibers into it does not increase the strength as compare to by adding micro silica.

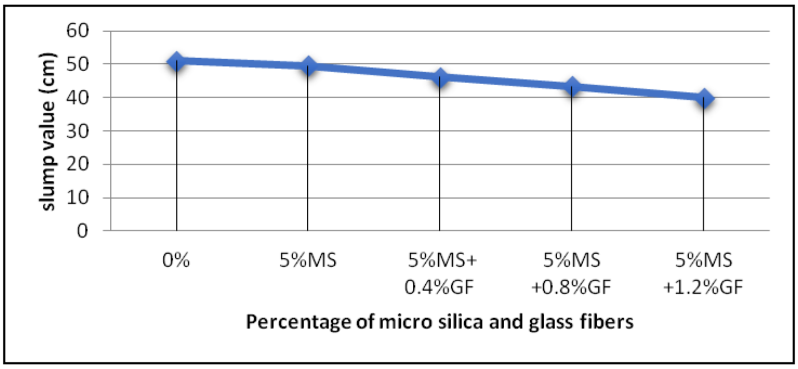

Fig. 1. Slump test for glass fiber concrete with micro silica

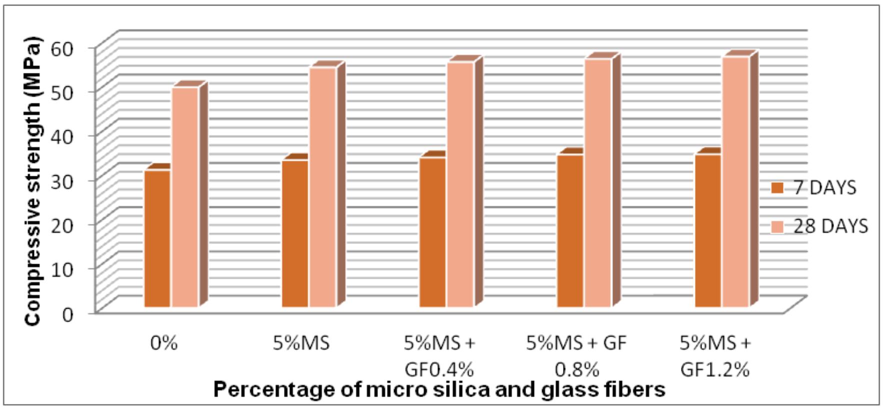

Fig. 2. Compressive strength of glass fiber concrete with micro silica

The compressive strength of cubes containing micro silica and glass fibers was observed as 49.95MPa, 54.45MPa, 55.68MPa, 56.36MPa and 56.88MPa respectively at 0%, 5%MS, 5%MS+0.4%GF, 5%MS +0.8%GF, and 5%MS +1.2%GF after 28 days of curing. Concrete's compressive strength of 28 days age cubes containing micro silica and glass fiber was increased by 8.26%, 2.20%, 1.20% and 0.91% which shows that adding micro silica at 5% will increase the compressive strength up to 8% and by adding both glass fibers and silica the strength will increased up to 12% as compared to controlled concrete.

5.3 Flexural Strength

The Fig. 3 establishes flexural strength of sample with w/c ratio of 0.36 with different proportions of micro silica and glass fibers as 0%, 5%MS, 5%MS+0.4%GF, 5%MS +0.8%GF, and 5%MS +1.2%GF after 28 days of curing.

From the figure it was seen that flexural strength of concrete is increased from 8.72MPa to 10.01MPa which is 12% higher than the controlled concrete. Similarly, the flexural strength is increases from 8.72 MPa to 12.68MPa which was 35% higher than the controlled concrete.

This significant increase in flexural strength with increasing fiber content is attributed to the random orientation of the fibers, the ability of the fibers to withstand some flexural loads, good bonding between the fibers and the concrete, and the high length-to-diameter [8]. This ratio allows the fibers to act like reinforcements.

5.4 Water Permeability Test

To determine the durability of concrete mixtures containing various proportions of glass fibers, and micro silica water permeability tests were performed on specimens size of 150 mm x 150 mm x 150 mm. Results are displayed in a below Fig. 4.

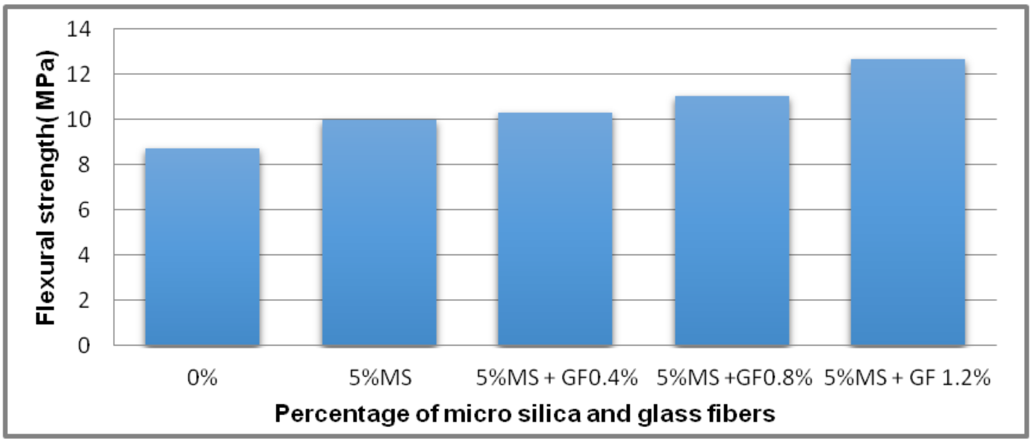

Fig. 3. Flexural strength of glass fiber concrete with micro silica

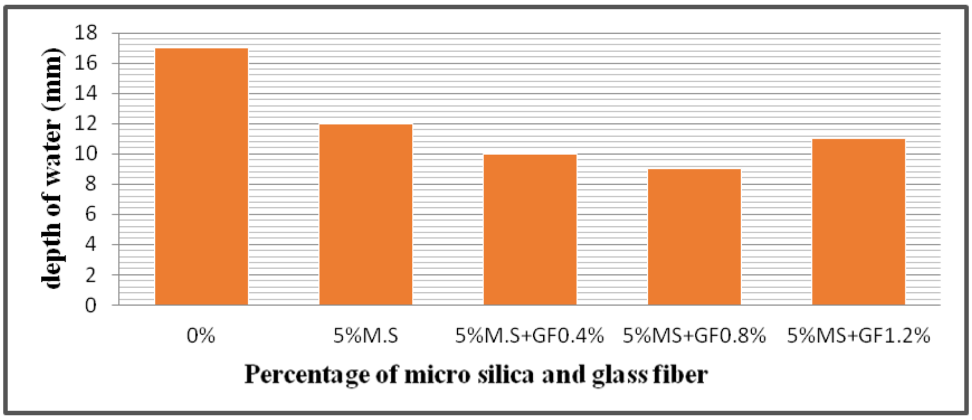

Fig. 4. Water permeability of glass fiber concrete with micro silica

Fig. 4 represent the water penetration depth of control and glass fiber concrete utilizing micro-silica in cement.

As a result of the permeability test, it was found that the permeability decreased from 17 mm to 12 mm when the micro silica exchange was changed from 0% to 5%. And it keeps going on decreasing side when both glass fibers and micro silica are added. All samples show less water penetration than the control mixture.

The action of pore filling with fine micro-silica enhances the pore structure of concrete, which lowers the water penetration in concrete, and may be the cause of the decrease in water penetration depth [2,15].

5.5 Drop Weight Impact Test

To determine the impact resistance of a glass fibre concrete mix with micro-silica, the impact resistance of the glass fibre reinforced concrete was tested. The results are shown in Fig. 5.

The impact resistance of glass fiber reinforced concrete with micro silica was evaluated by the use of drop weight machine. The impact strength of the samples containing glass fibers and micro silica in concrete with a w/c ratio of 0.36 after completion of curing for 28 days was measured as N1 and N2.

Where, N1 is number of the first visible crack and N2 is the number of hit that produces the ultimate smash.

The number of blows affecting first initial cracks was observed as 205, 215, 230, 240, and 255 at 0%, 5%MS, 5%MS+GF0.4%, 5%MS+GF0.8%, and 5%MS+GF1.2% added to concrete. The observed number of drops that ultimately failed was 220, 227, 255, 265, and 268 at 0%., 5%MS, 5%MS+GF0.4%, 5%MS+GF0.8%, and 5%MS+GF1.2% added to concrete.

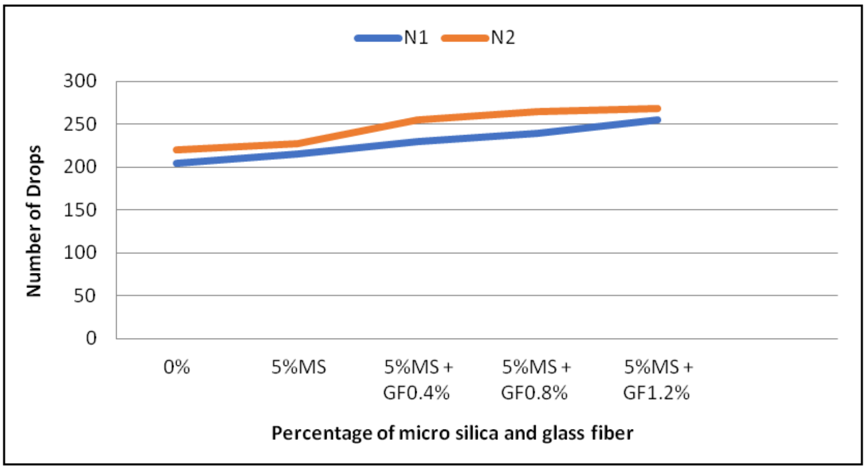

Fig. 5. Drop weight impact test of glass fiber concrete with micro silica

The results indicated that the impact increase with the addition of glass fiber and further increases by adding micro silica and glass fiber both. It shows that glass fibers absorb the post crack energy and improves the overall ductility of the concrete [16,17].

5.6 Bond Strength Test

In this study a total of five mixtures were prepared. One of these was a control mix with no fibers and micro silica, and the remaining four of his mix contained different levels of glass fibers with micro silica. The dosages used were 0%, 5% MS, 5%MS +0.4% GF, 5%MS + 0.8%GF, 5%MS + 1.2%GF of cement content and were added to concrete mix. The maximum pull-out load was recorded to calculate the final bond strength by assuming uniform bond stress distribution along the embedded length bar. Results are displayed in Fig. 6.

The bond stress between glass fiber reinforced concrete and steel was observed as 11.58MPa, 11.98MPa, 13.35MPa, 14.01MPa and 14.88MPa respectively at 0%, 5% MS, 5%MS +0.4% GF, 5%MS + 0.8%GF, 5%MS + 1.2%GF. From the results shown in Fig. 6 it is seen that the addition of glass fibers in concrete will increase the bond strength 22.17% as compare to controlled concrete. The reason behind the increase in bond strength of glass fiber reinforced concrete with micro silica over controlled concrete is that micro silica is pozzolonic material and it reacts with alkalis to form more cementing compounds.

5.7 Residual Compressive Strength at Elevated Temperature

After the samples were cooled to room temperature, residual compressive strength values for those exposed to elevated temperatures of 350 °C, 450 °C, and 650 °C were determined, as shown in Fig. 7.

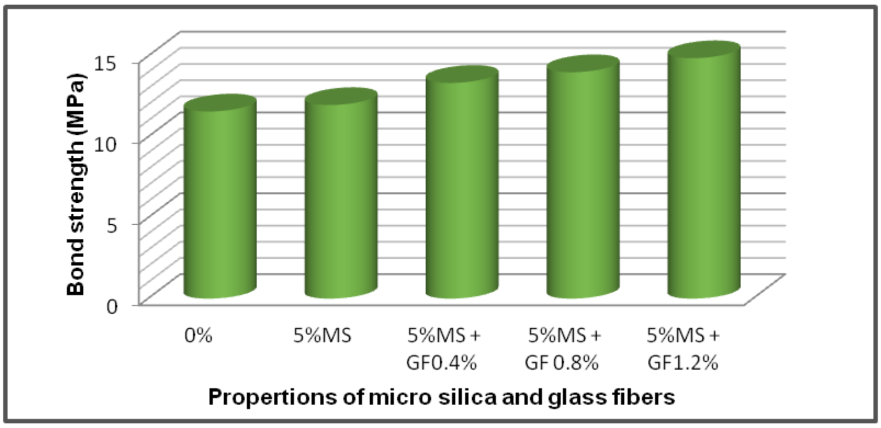

Fig. 6. Bond strength of glass fiber concrete with micro silica

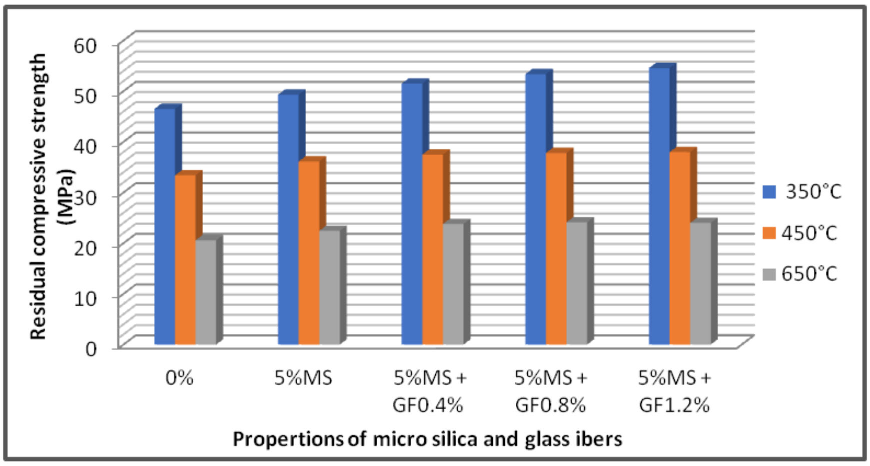

Fig. 7. Residual compressive strength of GFRC at elevated temperature

The residual compressive strength is demonstrated in Fig. 7 Concrete's compressive strength at 350ºC were observed as 46.5MPa, 49.3MPa, 51.5MPa, 53.35MPa and 54.55MPa respectively at dosages of 0%, 5% MS, 5%MS +0.4% GF, 5%MS + 0.8%GF, 5%MS + 1.2%GF. The residual compressive strength at 350°C is reduced by 6.90%, 9.45%, 7.50%, 5.34% and 4.09% in reference to the compressive strength at room temperature in control mix [18,19].

At 450 ºC temperature, the compressive strength of concrete carrying micro silica and glass fibers were observed as 33.39MPa, 36.12MPa, 37.48MPa, 37.8MPa, and 37.98MPa respectively at 0%, 5% MS, 5%MS +0.4% GF, 5%MS + 0.8%GF, 5%MS + 1.2%GF. The residual compressive strength at 450°C is reduced by 33.15%, 33.66%, 32.68%, 32.93% and 33.2% as compared to the compressive strength at room temperature in control mix.

The compressive strength of concrete at 650 ºC were observed as 20.58MPa, 22.43MPa, 23.78MPa, 24.12MPa and 24.86MPa respectively at different proportions of 0%, 5% MS, 5%MS +0.4% GF, 5%MS + 0.8%GF, 5%MS + 1.2%GF. It was seen from the result shown in Fig. 7 that strength is decreased by 58.7%, 58.8%, 57.2%, 57.2% and 56.2% with respect to the compressive strength at room temperature in control mix.

5.8 Micro Structure Analysis by SEM

The micro structural analysis of the glass fiber reinforced concrete was carried out to understand the microstructure of concrete mix. A scanning electron microscope is an electron microscope that creates an image of a sample by examines a surface with a focused electron beam. The microstructure of the three mixes were examined and compared with the nominal mix.

Fig. 8 demonstrates that the cement paste and aggregate in the control concrete has some amount of voids and gaps which can affect the strength of concrete. Gaps between cement paste and aggregate zone lead to lower mechanical performance of concrete SEM pictures of GFRC specimens are shown in below Fig. 9, it is seen that GF and cement matrix are bonded extremely strongly, which can be explained by the fact that glass fiber is a mineral fiber material with excellent hydrophilicity. The porosity was dropped by the glass fiber, which filled the holes on its surface and was carpeted in a forcefully solidified cement matrix [20].

Due to the excellent fiber-matrix bonding qualities, GF enhanced concrete strength properties and reduced water absorption. The GF filled the voids and covered its surface with a tightly adhered cement matrix, thus reducing the porosity. The existence of the GF prevented the elongation of the crack tip when fractures happened, due to the less density of the fiber and the small space among GF.

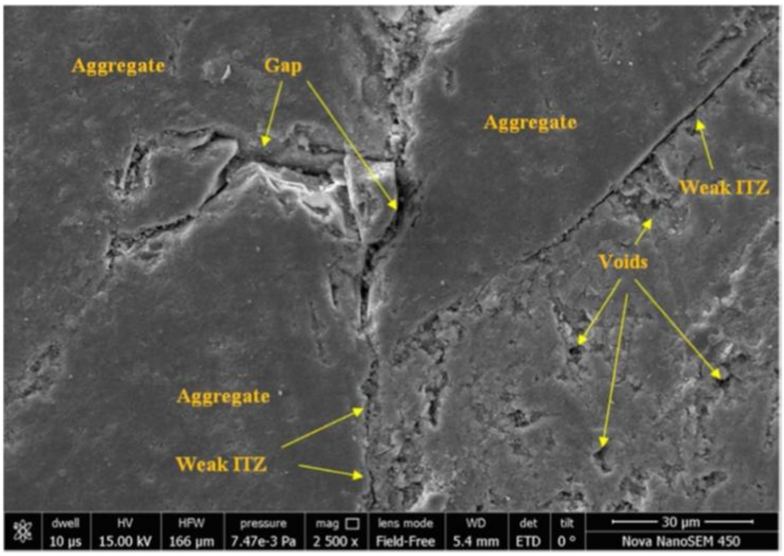

Fig. 8. SEM image of control mix

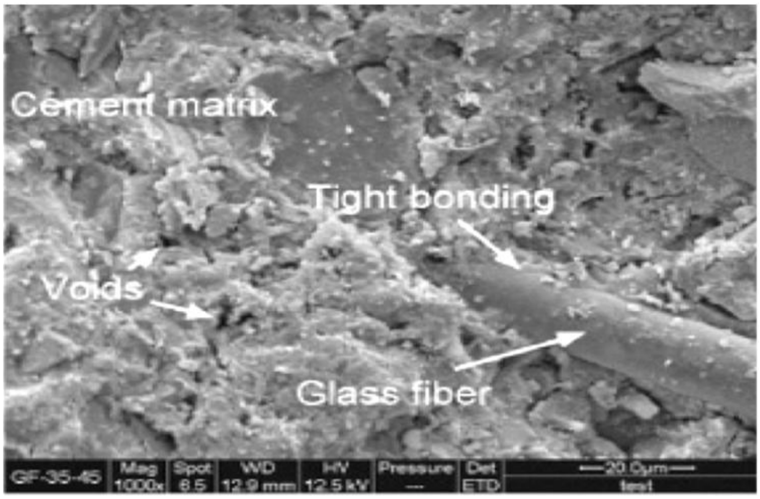

Fig. 9. SEM image of concrete with GF and micro silica

6. CONCLUSION

The focus of the current work is on glass fibre reinforced concrete that uses micro silica. There are multiple combinations employed, including 0%, 5% MS, 5%MS + 0.4% GF, 5%MS + 0.8% GF, and 5%MS + 1.2% GF.

The study's goal is to assess numerous mechanical and physical characteristics of concrete samples, including cement, water, fine and coarse aggregates, admixtures, micro silica, and glass fibres. Numerous tests, including the slump test, the compressive strength test, the flexural strength test, the water permeability test, the bond strength test, the compressive strength test when the temperature is enhanced, and the drop weight impact test.

The following conclusions can be drawn based on result obtained:

- The workability of glass fibers reinforced concrete significantly decreased as fiber content increased.
- According to research on the compressive strength of glass fibre reinforced concrete, the addition of micro silica by 5% to the concrete mix can increase compressive strength by about 8.2% over control concrete, and the addition of both micro silica and glass fibres can increase compressive strength by about 12% over control concrete.
- By adding 5% micro silica to concrete, its flexural strength rises by about 12.88%, and by combining it with 1.2% glass fibres and 5% micro silica, it increases by up to 31.23%. The ability of the fibres to sustain some flexural loads, the fibres' strong bond with the concrete, and the high length-to-diameter ratio all contribute to the improvement in flexural strength.
- The water penetration depth of all the samples with different percentages of micro silica and glass fibers is lower than the control specimens
- The impact resistance of glass fiber reinforced concrete with micro silica increases with increase in fiber content
- The bond strength between glass fiber reinforced concrete and steel increases by 22.17% when glass fibers are added over controlled concrete.
- With regard to the fire resistance test, the samples' compressive strength reduces as the temperature is continuously raised to higher levels. Compressive strength starts to decline when the temperature is raised further to 450 °C, and it starts decreasing severely at 650 °C.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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