EFFECT OF GLASS FIBER VOLUME AND MINERAL ADMIXTURE CONTENTS ON THE BEHAVIOR OF HPFRC

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Abstract: High performance concretes are being increasingly used for both on-land and offshore applications. However, these concretes were reported to be brittle compared to the normal concretes and this shortcoming can be overcome by the addition of short fibers to concrete. Glass Fiber Reinforced Concrete Composites (GFRCC) are being considered for some of the special applications in recent years, an understanding of the relationships between the different mechanical characteristics. In this study the Mechanical and durability properties of GFRCC were considered. GFRCC in compressions, flexure, split-tensile strength and durability were obtained and relation among them was developed. High Performance fiber reinforced Concrete mixes were made with cement replaced by fly ash and metakaolin in proportions of 20% and 10%. For each mix, cement was replaced by fly ash and metakaolin with fiber was replaced by 1% and 2%. High performance concrete in this study, were designed by modifying the ACI method (specified for normal concretes) and were produced using fly ash, Metakaolin and superplasticizer. In order to improve the durability properties many types of special concretes such as High Strength Concrete, High Performance Concrete, Fibre Reinforced Concrete, Self Compacting Concrete, etc. have been developed. High performance fiber reinforced concrete has become an attractive option to Civil Engineers due to the special characteristics like early strength, ease of placement, permeability, mechanical and durability properties. The mechanical properties such as cube compressive strength at the age of 7, 28 and 56 days, split tensile strength and flexural strength at the age of 28 days were determined. Based on test results, optimum replacement levels were obtained. The mechanical characteristics of high performance GFRCC, concretes were investigated considering concretes with compressive strengths ranging from 36 to 64 N/mm^2. The results of the compression and flexural studies indicate that the ductility of fiber reinforced concretes decrease with increasing compressive strength. The durability Higher grade concrete can be produced by adding fly ash and metakaolin. Limited literature is available on High Performance fiber reinforced Concrete (HPFRC) with glass fibers and fly ash and metakaolin. Hence, there is wider scope to conduct research investigation on HPFRC with1% and 2% replacement of glass fiber and fly ash and metakaolin. studies such as rapid chloride penetration test, saturated water absorption test, Moisture penetration and acid resistance at the age of 28 days for the typical mixes were also carried out. Durability is one of the most important parameters to be considered for GFRCC. These test results indicate that GFRCC have higher durability characteristics. The durability characteristics like Water absorption, moisture migration, Chloride ion penetration test and Acid attack. It was observed that all the concretes have satisfied the norms that were set to qualify them as high performance cementitious composites.

KEYWORDS: Glass fiber, fly ash, Metakaolin, strength, durability and high performance.

1. General

1.1. FIBER REINFORCED CONCRETE

Fibers have been utilized to reinforce brittle materials from times prehistoric, going back to the Egyptian and Babylonian times, if not prior. Straw was reinforced to strengthen sun-heated blocks and mud-hovel dividers, horsehair was reinforcing to fiber mortar and asbestos strands have been reinforcing to Portland cement mortars. Research by Romualdi and Batson (1963) and Romualdi and Mandel (1964) on firmly divided arbitrary fibers in the late 1950s and mid 1960s principally on Glass fiber proclaimed the time of utilizing fiber concrete composites as we probably aware them today. Furthermore, Shah and Rangan (1971), Swamy (1975), and a few different scientists in the United States, United Kingdom, and the Soviet Union set out on broad examinations around there, investigating different strands not withstanding Glass fibers. Further to expand the conceivable fields of uses of SCC, fiber might be added to the concrete. The expansion of fibers in concrete will settle these deficiencies of concrete (Barluenga and Hernandez-Olivares, 2007). Aydin (2007) investigated the effect of fiber inclusion on the SCC on the mechanical properties such as compressive, split and flexural strength of fiber reinforced SCC.

1.2. General Characteristics

The tensile strength of concrete is very low because plain concrete normally contains numerous micro cracks. It is the rapid propagation of these micro cracks under the applied stress that is responsible for the low tensile strength of the material. These deficiencies have led to a considerable research aimed at developing new approaches to modify the brittle properties of concrete through fiber additions. The addition of small, closely spaced and uniformly dispersed discrete fibers to concrete substantially improves many of its engineering properties such as tensile strength, flexural strength, fracture toughness, resistance to fatigue, impact, and thermal shock or spalling. The degree of enhancement of the properties of the hardened concrete depends upon the type, size, shape, volume fraction and aspect ratio of the fibers. The addition of fibers makes conventional plain concrete more versatile and flexible in method of production and more competitive as a construction material. Cement concrete reinforced with random fibers is called "Fiber Reinforced Concrete" or simply "Fibrous Concrete". The definition of Fiber Reinforced Concrete as given by ACI Committee-544 (1985) is, "Fiber Reinforced Concrete is concrete made of hydraulic cements containing fine or fine and coarse aggregates and discontinuous discrete fibers".

1.3. GLASS FIBER REINFORCED CONCRETE

Though there is a limited amount of research work available in glass fibers, the work carried out by researchers show that there glass fibers could be of potential use in wide variety of engineering applications. Daiane Romanzini et al (2012) studied the effects of changes in chemical composition and thermal stability of the glass fibers after washing with distilled water and found that by increasing the relative volume fraction of glass fiber until an upper limit of 75%, higher flexural and impact properties were obtained. In this research (19) Addition of glass fiber in reinforced concrete increases the toughness by using fiber content 0.67% and 1.25% . The percentage increase of compressive strength of various grades of glass fiber concrete mixes compared with 28 days compressive strength is observed 37%. The percentage increase of flexure strength of various grades of glass fiber concrete mixes compared with 28 days compressive strength is observed 5.19%.

2. LITERATURE REVIEW

Suryawanshi [2007]. HPC was more homogeneous than normal strength concrete (NSC). Initial flaws like pores, cracks and interfacial delamination in HPC were smaller and less numerous than in NSC. This made HPC more stiff and elastic as compared to NSC. The non-linear part in the ascending branch of the stress strain diagram and the post-peak softening part were reduced which was a sign of brittleness. However, when HPC was confined by reinforcement it became ductile.

Hui-sheng et al. [2009] experimentally investigated the compressive strength, gas permeability and carbonation of HPC with fly ash (FA) or ground granulated blast furnace slag (GGBFS) and analyzed the relationships among them. Test results showed that influences of FA with replacement up to 60%on the properties investigated are significantly affected by water–binder (w/b) ratios. Moreover, HPC with GGBFS showed much better performance than that with FA at the same w/b ratio. The relationship between compressive strength and gas permeability of HPC greatly depends on w/b ratios and mineral admixture types.

Shaohua Zhang (2018) Strain rate studies of pultruded glass fiber reinforced polymer (GFRP) material properties. Similar to GFRP laminates nonlinear behaviour of pultruded GFRP occurs at high strain rates. By contrast, almost linear elastic behaviour appears at quasi-static strain rates. The boundary between these behaviours around the intermediate strain rate range is not yet known well, and so further experimental work is required.

George Wypych (2013) Glass fiber reinforced concrete was subjected to experimental weathering studies and model simulations. It was concluded that hot water aging is not a suitable method of testing, especially at temperatures higher than 65°C which may activate processes not observed in natural weathering.

2.1. Mechanical properties of glass fiber reinforced concrete

2.1.1 Compressive Strength

The compressive properties of fiber-reinforced concrete (FRC) are relatively less affected by the presence of fibers as compared to the properties under tension and bending. The compressive strength of concrete is commonly used in the design of concrete structures. It is used for specifying, controlling and evaluating concrete quality. The strength of concrete depends on a number of factors, namely, the properties and proportions of the constituent materials, degree of hydration or age of testing, specimen geometry, method of testing and rate of loading.

The influence of fibers in improving the compressive strength of the matrix depends on whether mortar or concrete (having coarse aggregates) is used and on the magnitude of compressive strength. Studies prior to 1988 including those of **Williamson (1974), Naaman et al. (1974)** showed that with the addition of fibers there is an almost negligible increase in strength for mortar mixes; however for concrete mixes, strength increases by as much as 23%. Furthermore, **Otter and Naaman (1988)** showed that use of glass fibers in lower strength concretes increases their compressive strength significantly compared to plain unreinforced matrices and is directly related to volume fraction of glass fiber used. This increase is more for hooked fibers in comparison with straight glass fibers, glass or polypropylene fibers.

Bayasi and Zeng (1993) reported that when glass fibers with fiber lengths of 0.5 in. (12.5 mm) and 0.75 in. (19 mm) were used in volume fractions of 0.1, 0.3 and 0.5%, there was no significant effect on the compressive strengths.

Soroushian et al. (1992) reported that the glass fibers decreased the compressive strength of concrete materials; with 0.1 percent volume fraction of glass fibers, the average compressive strength was 23 percent less than the corresponding values for plain concrete.

2.1.2. Tensile Strength

Siddharth Patela and R.S. Ranab et al (2017) Study on mechanical properties of environment friendly Aluminium E-waste Composite with Fly ash and E-glass fiber .The 20% of fly ash sample got higher hardness and decrease in frictional forces and wear rates. So by increasing fly ash%, hardness gets increased. Tensile strength, yield strength and compressive strength increases by addition of the fly ash with having constant e- glass fiber. Percentage of elongation, Hardness also increases by addition of fly ash but only the 6% fly ash sample lowers in hardness and % of elongation compared with the other samples. Toughness only decreases by the addition of the fly ash.

Mirza and Soroushian (2002) studies show similar influences of Glass fiber (GF) on the strength of concrete. It shows that split tensile and flexural strength are increased with increase of GF content. But GF content increased beyond 0.8% reduces the workability of concrete due to inter friction between fibers and aggregates.

Barluenga and Hernandez-Olivares (2007) developed SCC with inclusion of AR glass fiber. They conducted compression, flexural strength tests and free shrinkage tests with and without air flow over the sample and double restrained slab cracking tests to assess the cracking control ability of AR glass fiber. They described that the inclusion of low amounts of fiber did not modify the flowability and mechanical properties of concrete. They concluded that less amount of glass fiber showed the maximum cracking control ability, but larger amounts did not increase the fiber efficiency.

2.1.3. Flexural strength

Bayasi and Celik (1993). The specimens were 100 x 100 x 500 mm (4 x 4 x 20 in.) and were subjected to a centre point load flexural load-deflection behavior test over a span of 500 mm (20 in.) according to ASTM C 78 and C 108. Two fiber types were used: fibrillated glass fibers and polyethylene-terphalate polyester fibers. Fiber volume fractions ranged from 0 to 0.6% and fiber length was 12 mm (0.5 in.). The results indicate that polyester fibers and glass fibers have an inconsistent effect on the flexural strength but significantly increase the flexural toughness and the post-peak resistance of concrete.

Bayasi and Zeng (1993) proposed that flexural behavior of glass fiber be characterized by the post-peak flexural resistance (load or stress). It was found that, for volumes equal or less than 0.3 percent, 19 mm (0.75 in.) long fibers were more favorable for enhancing the post-peak resistance. For 0.5 percent volume, 12.5 mm (0.5 in.) long fibers were more effective.

Balaguru (1992) also investigated the flexural strength and the flexural load-deflection behavior of polymer-fiber reinforced rapid-setting concrete. The test variables were the matrix type and fiber type. The first product was a portland cement with a pozzolanic addition termed.

2.1.4. Durability

Abrasion tests **(Nanni 1989)** in accordance with ASTM C 799, procedure C, on field–cut and laboratory–made specimens showed no significant difference between the abrasion resistance of plain concrete and steel or synthetic fiber-reinforced concrete. However, the results indicated beneficial effects of glass fibers on scaling prevention of existing pavements **(Nanni and Johari 1989)**. As pointed out by ACI Committee 544 (1982, 1988, 1990), abrasion as it relates to pavements, and slabs, wear under wheeled traffic is similar to the low velocity erosion in hydraulic structures where the presence of fibers is not expected to increase the abrasion resistance of concrete.

As pointed out by ACI Committee 544 (1982, 1988, 1990), the addition of fibers themselves has no significant effect on the freezing and thawing resistance of concrete. That is, concretes that are not resistant to freezing and thawing will not have their resistance improved by the addition of fibers (Schupack 1985; Hoff 1987). Hence, the well-known practices for achieving durable concrete and the same air entrainment criteria for plain concrete should be used also for fiber reinforced concrete.

Ramakrishnan (1986), developed the understanding that the addition of entrained air improves the freeze/thaw durability of FRC in a manner similar to that of plain concrete. Based on their experimental results, Balaguru and Ramakrishnan (1986) proposed that for a w/c of more than 0.4 (for most field applications) and cement content less than 700 pcy (415 kg/m^3), a minimum of 6% (preferably 8%) entrained air should be used to improve the freeze/thaw resistance of fiber reinforced concrete.

The effect of addition of glass fiber to concrete mix and adequate curing in enhancing the detoriation resistance of concrete surface skin subjected to cyclic wet/dry seawater exposure was evaluated (Al-Tayyib and Al-Zahrani 1990).

2.2. Objectives

In perspective on this, the objective of the present investigation can be condensed as followings.

- To develop M_{50} grade HPFRC and to study the effect of glass fibres on the mechanical properties of HPFRC.
- It is proposed to extend or modify the available normal concrete mix design data to the design of high performance concretes. It is develop the relationships between the compressive strength and other mechanical properties (compressive, flexural and splitting tensile strength, etc.) of the high performance plain and fiber reinforced concretes.
- Assess the behaviour of glass fibers in concrete.
- The effect of matrix compositions with mineral admixtures.
- Develop a synergistic mixed fiber reinforced cementitious composites.
- The effect of curing methods on GFRCCs.
- To evaluate the durability parameters of GFRCC and to compare them with the requirements as per the International Codes of practice.
- Assess the impacts of differ types of mineral admixtures and distinctive fiber volume content on the mechanical behaviour of high performance concrete (HPC).

2.3. Scope

Review of literature indicated that addition of fibres improved the strength and behaviour of conventional concrete significantly. While large number of investigations is available in literature on the effect of fibres on the strength and behaviour of conventional RCC structural beams the effect of combination of fibres such as glass fibres on the behaviour of HPFRC structural elements have not been come across. Taking note of the above gap in the existing knowledge, an attempt is made to study the strength and behaviour of HPFRC structural elements under compression, tension, and flexure. In addition, there is a need to assess the durability of HPFRC so that the material can be confidently used in regular constructions.

- The scope of the present work was to find out mechanical properties of HPFRC when the replacement of cement with fly ash and metakaolin by 20% and 10% and also systematically study the effect of glass fiber replacement of 1% and 2% respectively on propertied of concrete.
- The study was carried on HPFRC designed with 0.38 water cement ratio.

3. RESULTS AND DISCUSSION

3.1. Compressive strength Results

Table.3.1 Results of compression strength (N/mm²) of concrete

SI.NO	Mix Designation	Compressive strength (N/mm²)		
		7 Days	28 Days	56 Days
1	HPC	36.47	51.23	54.5
2	HPCF	37.50	52.17	57.0
3	HPCM	38.80	52.38	60.0
4	HPCF+1%fiber	41.78	53.13	62.0
5	HPCF+2%fiber	39.00	54.41	62.5
6	HPCM+1%fiber	36.70	52.75	55.0
7	HPCM+2%fiber	49.75	56.53	64.0

3.2. Tensile Strength Results

Table3.2. Results of split tensile strength (N/mm²) of concrete

SI.NO	Mix Designation	Split tensile strength (N/mm²) 28 Days
1	HPC	5.28
2	HPCF	5.47
3	HPCM	5.54
4	HPCF+1%fiber	5.56
5	HPCF+2%fiber	5.63
6	HPCM+1%fiber	5.76
7	HPCM+2%fiber	6.04

3.3. Flexural strength test results

Table.3.3. Results of flexural strength (N/mm²) of concrete

SI.NO	Mix Designation	Flexural strength (N/mm²) 28 Days
1	HPC	6.25
2	HPCF	6.60
3	HPCM	6.65
4	HPCF+1%fiber	6.80
5	HPCF+2%fiber	7.15
6	HPCM+1%fiber	7.20
7	HPCM+2%fiber	7.38

3.4. Durability Properties

3.4.1. Water absorption test results

The absorption characteristics which indirectly reflect the permeability show that the initial half hour absorption values for all the concretes were lower than limit specified for good concrete by Concrete Society (CEB, 1989). Absorption values of fiber concrete is less when compared to convention concrete and lowest absorption value is absorbed at 1% replacement of glass fiber with 20% replacement of fly ash.

An assessment criterion for absorption as proposed is shown in Table 3.5. The results of absorption study for GFRCC presented in Table 3.5 Figure 3.5. shows the variation of absorption with time. Structure this it very well may be seen that the retention was practically same for every one of the concretes at first. It was noticed that only at later periods the absorption was increasing the variation of absorption percentage at 1/2 and 72 hours of all the mixes. The 30 minutes absorption values of all the concretes were falling below 3% which indicating good quality concretes as per CEB – FIP (1989).

Table 3.4 Assessment criteria for absorption (CEB, 1989)

Absorption (% @ 30 min.)	Absorption rating	Concrete quality
<3.0	Low	Good
3.0 to 5.0	Average	Average
> 5.0	High	Poor

Table 3.5 Results of water absorption test

SI.NO	Mix Designation	Initial weight (gms)	Weight gain (%) / Time(hrs)					Final weight (gms)
			0.30	6	24	48	72	
1	HPC	2492	2.046	1.244	0.642	0.140	0.281	2499
2	HPCF	2409	1.951	1.287	0.996	0.141	0.266	2413
3	HPCM	2407	2.700	1.786	0.457	0.830	0.457	2418
4	HPCF+1%fiber	2473	2.022	1.334	0.566	0.162	0.202	2478
5	HPCF+2%fiber	2363	2.624	1.650	1.143	0.254	0.254	2369
6	HPCM+1%fiber	2356	2.711	2.165	0.382	0.339	0.424	2366
7	HPCM+2%fiber	2379	2.816	2.018	1.639	1.975	0.294	2380

3.5. Moisture migration test results

The moisture migration test results, measured in terms of moisture rise in 'mm' with time and the percentage weight gain with time were presented for glass concretes in Tables 3.6. Figure3.6 shows the moisture migration of glass concretes with time from this it can be observed that moisture migration is more only during first 30 minutes later the migration is becoming almost constant with time.The variation of final weight gain of moisture migration. From these outcomes it very well may be construed that the weight gain was diminishing with the expansion in compressive strength. The Moisture characteristics which indirectly reflect the permeability show that the initial half hour absorption values for all the concretes were lower than limit specified for good concrete by Concrete Society (CEB, 1989). Absorption values of fiber concrete is less when compared to convention concrete and lowest absorption value is absorbed at 1% replacement of glass fiber with 20% replacement of fly ash.

Table 3.6: Moisture migration characteristics of concrete (mm/time (hrs)

SI.NO	Mix Designation	Initial weight (gms)	Moisture migration (mm) / Time(hrs)					Final weight (gms)
			0.30	6	24	48	72	
1	HPC	2442	9.625	20.000	25.625	32.500	35.625	2507
2	HPCF	2341	11.625	24.375	33.750	33.125	28.750	2399
3	HPCM	2331	12.125	29.375	27.500	31.250	20.000	2394
4	HPCF+1%fiber	2402	3.750	22.500	28.125	27.500	12.500	2456
5	HPCF+2%fiber	2322	13.750	30.625	40.000	40.000	28.125	2381
6	HPCM+1%fiber	2354	20.000	36.250	48.750	52.500	38.750	2413
7	HPCM+2%fiber	2388	12.500	30.000	27.500	40.000	32.500	2439

3.6. Acid attack test results

The results of the parameter studied as weight loss for all concretes were presented in Table 3.7. The typical weight loss due to acid attack with immersion period for HPFRC concrete. The weight change at the end of 28 days for all these concretes was also presented in Figure 3.7. It can be seen that fiber concrete showed lower weight loss compared to normal concrete, but at lower strengths the variations in weight loss between these concretes were only marginal. At higher strengths the glass fiber concrete performed better compared to normal concretes. In general, it can be seen that, weight loss was decreasing with increasing percentage replacement upto 1% of glass fiber with 10% replacement of metakaolin. The percentage of loss in mass due to acid attack is given in the Table 3.7. For GFRHPC, percentage loss of mass is less compared to HPC. However, the loss in weight is higher for GFRHPC, owing to the corrosive nature of glass fibers in acidic environment.

Table 3.7 Effect of acid attack on concrete investigated

SI.NO	Mix Designation	Initial Weight (gms)	Immersion period (5% H_2SO_4) Weight loss (%)		
			7 Days	14 Days	28 Days
1	HPC	2476	2.504	5.452	7.245
2	HPCF	2388	5.234	7.621	9.357
3	HPCM	2390	7.741	11.046	12.456
4	HPCF+1%fiber	2429	6.464	9.469	10.354
5	HPCF+2%fiber	2381	5.669	10.038	11.784
6	HPCM+1%fiber	2384	1.299	4.809	6.876
7	HPCM+2%fiber	2480	6.734	10.362	11.451

3.7. Chloride Ion Penetration Test results

From the results indicate that fiber concretes show a very low resistance to chloride ion penetration in percentage replacement upto 2% of glass fiber with 20% replacement of fly ash. It proves that use of fiber in concretes as supplementary cementitious materials, enhances the durability and corrosion characteristics of concrete and in particular will be effective in marine environment.

Table.3.8. Chloride ion penetrability based on charge passed

Charge passed (coulombs)	Chloride ion penetrability
> 4000	High
2000 – 4000	Moderate
1000 – 2000	Low
100 – 1000	Very low
< 100	Negligible

Table3.9. Results of chloride ion penetration test

SI.NO	Mix Designation	Charge passed (coulomb)	Chloride ion penetrability as per ASTM C1202[197]
1	HPC	430.5	Very low
2	HPCF	450.0	Very low
3	HPCM	432.8	Very low
4	HPCF+1%fiber	1078.9	Low
5	HPCF+2%fiber	380.2	Very low
6	HPCM+1%fiber	1175.0	Low
7	HPCM+2%fiber	1300.0	Low

3.8. Summary

- It was observed that in Tables3.1. Figure 3.1 shows the addition of glass fibers increased the compressive strength by almost 78% at 2% (by volume) and at higher fiber percentages.
- Similar observation was also made in terms of the split tensile strength. However, in Tables 3.2. Figure3.2 shows at 2% fiber content the increase in split tensile strength was almost 87% compared to the normal matrix (without fiber).
- This study clearly shows that the optimum fiber percentage was 2% and higher percentages addition of glass fiber will not be of much help in improving the matrix.
- Similar observation was also made in terms of the flexural strength. However, in Tables 5.3. Figure5.3 shows at 2% fiber content the increase in flexural strength was almost 84% compared to the normal matrix (without fiber).

- The durability characteristics were studied in the present chapter. The durability characteristics like absorption, moisture migration, chloride ion penetration test, and acid attack were investigated. The summary of results of present study is as follows

- The absorption characteristics in Tables 3.4. Figure3.4 shows which indirectly reflect the permeability for glass fiber composites at 30 minutes were ranging from 1.95 – 2.88%. These fall under the good concrete category as per CEB-FIP limit.

- Moisture migration values varied between 10 - 52 mm in height and weight gain was observed in Tables 3.5. Figure3.5 shows to be between 2.28 – 2.499 % the maximum weight gain was observed in conventional concrete.

- All the mixed fiber concrete composites showed higher resistance to chloride ion diffusion. All the concretes were assessed as very low chloride permeability concretes as per ASTM C1202-94 assessment criteria. The total charge was in Tables 3.6. Figure3.6 shows in the range of 430 – 1300 coulombs and these values are well below the 1000 coulombs for good concretes.

- The effect of acid attack was assessed by weight loss. The results clearly in Tables 3.7. Figure3.7 shows that weight loss was decreasing with increasing fiber percentage replacement, but the differences were only marginal. In general, the fiber concretes showed better resistance to acid attack and also the attack rate was reducing with increasing percentage of replacement.

4. SUMMARY AND CONCLUSIONS

The significant conclusions based on the results and discussions presented in the preceding chapters are summarized briefly here under.

1. It was observed that the addition of glass fibers increased the compressive strength (78%) upto 2% by volume and at higher fiber percentages, This study clearly shows that the optimum fiber percentage was 2% and higher percentages addition of fiber will not be of much help in improving the matrix.
2. Similar observation was also made in terms of the split tensile strength for GFRCC however, at 2% fiber content the increase in split tensile strength was almost 87% compared to the normal matrix (without fiber).
3. Similar observation was also made in terms of the flexural strength for GFRCC however, at 2% fiber content the increase in flexural strength was almost 84% compared to the normal matrix (without fiber).
4. The glass fiber reinforced composites show the highest toughness characteristics at 1.0 and 2.0% levels. The residual strength factor also shows a similar trend. However, the first crack toughness did not seem to get influenced by the fiber percentage.

5. The absorption characteristics which indirectly reflect the permeability for glass fiber composites at 30 minutes were ranging from 1.95-2.88% These fall under the good concrete category as per CEB-FIP limit.

6. All the glass fiber concrete composites showed higher resistance to chloride ion diffusion. All the concretes were assessed as 1ow and very low chloride permeability concretes as per ASTM C1202-94 assessment criteria. The total charge was in the range of 430-1300 coulombs.

7. The deterioration characteristics of these concretes, assessed in 5% H_2SO_4, show that weight loss was decreasing with increasing fiber percentage replacement. In particular, fiber concretes performed better than normal concrete.

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