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Research Article

Mechanical and durability properties of cement mortar and concrete reinforced with glass micro fibre

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Abstract

Concrete is the most commonly used construction material across the globe. In view of achieving sustainable development, the use of blended cements is becoming more prominent nowadays. Many research studies are being carried out across the globe on addition of different additives to enhance the properties of cement and concrete which also includes different types of fibrous materials. In this study, the effect of addition of glass microfiber on physical and chemical properties of PPC was studied for 0.2%, 0.4% and 1.0% by weight of cement. Mechanical properties such as compressive strength, flexural strength, modulus of elasticity, split tensile strength and drying shrinkage of concrete made with PPC cement with and without glass microfiber at water to cement ratio of 0.50 were studied. Durability properties such as RCPT and air permeability were also evaluated. For study at elevated temperatures, concrete samples were exposed to temperatures of 200ºC and 600ºC for duration of 1 hour. From the experimental investigation carried out, compressive strength was observed to improve by 13.6 % for PPC containing glass microfiber in comparison to control PPC. Reduction in cracks due to plastic shrinkage of concrete was observed on addition of glass micro fibre in PPC. Drying shrinkage of concrete was observed to decrease on addition of glass micro fibre in PPC. Other mechanical and durability properties of concrete made with PPC with and without glass micro fibre were observed to be comparable. No significant improvement in mechanical properties due to addition of glass micro fibres was observed upon exposure of concrete to elevated temperatures.

1. Introduction

Portland Pozzolana Cement (PPC) is manufactured in two different ways, either by interblending or by inter grinding. During the interblending, the individual raw materials such as fly ash, clinker, gypsum are ground separately and further blended in certain fixed proportions. Whereas in inter-grinding approach, raw materials such as clinker, gypsum and fly ash (i.e. pozzolanic materials) are added in certain fixed proportions and ground together in a single grinding unit to produce PPC. Pozzolanic materials (for example, calcined clay and fly ash) possess little cementitious properties in itself. However, they contain alumino silicates and thereby, react with calcium hydroxide (produced as by-product during the hydration of clinker) in the presence of water to produce compounds similar to calcium silicate gel hydrate (as produced in case of hydration of clinker).

The practice of usage of fibrous materials in construction sector is not a new concept as it has been adopted by construction fraternity from past several decades in different ways.

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Researcher Joseph Lambot patented technology of usage of fibers in cementitious mixtures in year 1847. Further, technology of development of Fibre Reinforced Composites (FRC) was written about and patented during 1960's by Naaman [1]. History and development of FRC has also been discussed in detail in book authored by Balaguru and Shah [2]. In present scenario, reinforcing fibres are being made up of different materials and can be broadly categorized in four classes: mineral fibre (for example: glass and asbestos), steel fibre, synthetic organic fibre (made up of polymer, carbon or cellulose) and natural fibres (from plant and animals). The most popular type of fibre among above mentioned fibres for usage in structural and non-structural applications is steel fibre [3, 4].

The overall resultant performance of any fibre reinforced system varies with the kind of the cementitious matrix (it may be cement paste, cement mortar or concrete) used for binding the fibres used for reinforcement. This happens due to the variation in complexity of individual system. As we move from cement paste towards concrete, the complexity of the system gets increased as cement paste is made up of only cement and water, whereas a cement mortar mix comprises of cement, water and well graded fine aggregate, and a concrete mix consists of cement, water, fine and coarse aggregate along with chemical admixtures. Johnson et al [5] suggested that addition of coarse aggregate in the matrix of a fibre reinforced composite leads to reduction in the efficacy of the fibres in the system as it causes reduction in the proportion of fibre in overall composite. Hence, inclusion of fibre is considered to be more effective in cement paste and cement mortar systems.

The inclusion of different types of fibres in cement based fibre reinforced composites has several benefits as it leads to improved performance against phenomena such as shrinkage and creep along with reduction in cost [6]. However, few studies have revealed and highlighted that addition of micro fibres caused decrease in compressive strength of mortar containing micro fibre in comparison to control mortar (without any micro fibre). This may be the result of increased air content of experimental mixes (containing micro fibre) in comparison to control mixes. However, the mechanism leading to increase in air content in the mix due to inclusion of fibre is not yet fully explained [6]. Erdogmus et al [7] observed both decrease as well as increase in compressive strength of fibre reinforced composite in comparison to control cementitious composite (without any fibre). They discussed the mechanism behind the occurrence of these two phenomena. According to them, when the fibre reinforced specimen dilates laterally under compressive load and tensile stresses get developed, then the fibres in horizontal orientation bridge the cracks generated due to tensile stresses and therefore lead to improvement in compressive strength of composite. On the contrary, inclusion of fibres in the composite leads to generation of air voids and the fibres of vertical orientation may get snapped due to occurrence of tension in horizontal direction and thereby, reducing the performance of fibre reinforced composite again compressive load [8-10].

Rath et al [11] reported reduction of early-age shrinkage by 57% in comparison to the control concrete mix on addition of 0.1% of glass fibre by volume of concrete. This behaviour was attributed to high tensile strength of glass fibre. Inclusion of glass fibres provides a medium for stress to be transferred across shrinkage cracks, thereby providing crack bridging which ultimately prevents the crack growth. Apart from reduction in shrinkage, improvement in compressive and flexural strength was also reported. Rath et al further reported through another study [12] that shrinkage value of fibre reinforced geopolymer concrete is 44% lesser in comparison to conventional geopolymer concrete. Further, it was recommended that glass fiber shall be used in geopolymer concrete mix containing brick aggregates for compensating loss of compressive strength occurring due to replacing stone aggregate with brick aggregate.

Several research studies conducted in past, indicate that use of fibers has detrimental effect on the mechanical properties of fibre reinforced concrete when exposed to elevated temperature as addition of fibres significantly reduced the both compressive and tensile strength along with modulus of elasticity [13-16].

2.Research Significance

Majority of the research works conducted in the past to study and investigate the effect of addition of fibre in cement and concrete matrices has been conducted using steel fibre and poly propylene fibres. Very scarce and limited research literature is available on effect of glass micro fibres in cement and concrete matrices. The present research study aims to study the effect of addition of glass micro fibres in fly ash based Portland Pozzolana Cement and concrete prepared using both control PPC (without glass micro fibre) and PPC containing different dosages of glass micro fibre.

3. Experimental Program

In this study, PPC complying with IS: 1489-2015 was used as cementitious material. PPC used in this study is referred to as PPC-0 to represent PPC without micro fibre. PPC-0 was mixed with 0.2% (P-MF-0.20), 0.4% (P-MF-0.40) and 1% (P-MF-1.0) glass micro fibre by weight of cement. Mixing was performed in ball mill using ceramic balls for a duration of 30 minutes. Glass micro fibres with diameter of 14 microns and cut length of 4 mm were used for this study. All these cements were evaluated for physical and chemical properties as per IS 1489: 2015 and were compared with control PPC (PPC-0). Concrete mixes having cement content of 340 kg/m3 were prepared at water cement ratio of 0.50 and using PPC-0, P-MF-0.20 and P-MF-0.40 using Naphthalene based super plasticizer (chemical admixture). Concrete mixes were evaluated for fresh properties such as slump, air content, bleeding and plastic shrinkage. Engineering properties of hardened concrete such as compressive strength, flexural strength, split tensile Strength, modulus of elasticity and drying shrinkage were also evaluated. Microstructure study using SEM was also conducted to investigate any ITZ refinement. Durability properties such as Rapid Chloride ion penetrability test and air permeability tests were also carried out. Mechanical properties of concrete sample cast using PPC-0, P-MF-0.20 and P-MF-0.40 after exposing concrete at 200 ºC and 600 ºC were analyzed to evaluate the performance of concrete exposed to high temperature.

4. Methodology

Methodologies adopted for evaluation of different parameters for cement, aggregates and concrete mixes are as mentioned below:

4.1. Concrete Ingredients

All the Portland Pozzolana Cement (PPC) cement samples were evaluated for different chemical (such as loss on ignition, Magnesia, Sulphuric anhydride, insoluble material) and physical parameters of PPC specified in IS 1489 (Part-I): 2015 [17]. Chemical and physical parameters were evaluated as per IS 4032: 1985 [18] and IS 4031: 1996 [19] respectively. Test results have been tabulated in Table 1 and Table 2. The coarse and fine aggregate samples used for preparation of concrete mixes were tested as per IS 2386: 1963 [20] for various physical parameters mentioned in IS 383-2016 [21]. Crushed aggregate with a maximum nominal size of 20 mm was used as coarse aggregate and natural river bed sand confirming to Zone II as per IS: 383 was used as fine aggregate. The petrographic studies conducted on coarse aggregate indicated that the aggregate sample is medium grained with a crystalline texture and partially weathered sample of calc-granulite. The major mineral constituents were quartz, biotite, plagioclase-feldspar and orthoclasefeldspar. The silt content in fine aggregate as per wet sieving method is 0.85 percent. Naphthalene based super plasticizer (chemical admixture) complying with requirements of Indian Standard is used for preparation of all the concrete mixes and its dosage was varied for individual mixes to keep initial slump of concrete in the range of 100 to 150 mm. Water complying with requirements of IS: 456-2000 for construction purpose was used.

4.2. Glass Micro Fibre and Microstructure Analysis of Concrete

Length and diameter of glass microfibre and microstructure analysis of hardened concrete was investigated using scanning electron microscope (SEM) JEOL-6510 with secondary electron image detector. The maximum attainable magnification with the above instrument is 1 Lacs. The morphological studies of samples were carried out at different magnifications such as 250x, 500x, 1000x, 1500x, 2000x, 4000x, 5000x and 8000x. The power of electron gun is 20KV of electron gun and sopt size of the analyzed images is 30.

4.3. Engineering Properties of Fresh Concrete

Fresh properties of concrete such as slump test, air content and Plastic Shrinkage test were evaluated for all the concrete mixes. Slump test and air content of concrete mix were evaluated as per IS 1199: 1959 [22]. Plastic shrinkage was evaluated as per ASTM C1579 [23] and crack width was measured using crackoscope.

4.4. Engineering Properties of Hardened Concrete

Compressive strength test was conducted on concrete cubes (of size 150 mm × 150 mm × 150 mm) as per IS; 516 (Part 1) Sec-1: 2021 [24] at the age of 7 and 28 days. Flexural strength test was conducted (as shown in Figure 1) on concrete beam (of size 500 mm × 100 mm × 100 mm) as per IS: 516 (Part 1) Sec-1: 2021 at the age of 7 and 28 days. Split tensile strength test was conducted on concrete cylinder (of size 150 mm diameter and 300 mm height) as per IS 5816: 1999 [25] at the age of 7 and 28 days. Test for Modulus of Elasticity was conducted on concrete cylinder (of size 150 mm diameter and 300 mm height) as per ASTM C 469 at the age of 28 days. Sample being evaluated for Modulus of Elasticity been shown in Figure 2. Drying shrinkage test was conducted on concrete beam (of size 75 mm × 75 mm × 300 mm) as per IS 1199: 2004.

Fig .1 Sample undergoing flexural strength test

Fig. 2 Sample being tested for modulus of elasticity

4.5. Durability Properties of Concrete

Concrete mixes were evaluated for durability properties such as Rapid Chloride Penetration Test (RCPT) and air permeability test. Methodologies adopted for these tests are as mentioned below:

4.6.1. Rapid Chloride Ion Permeability Test (RCPT)

RCPT is used to evaluate the concrete making materials against the chloride ion penetration as per ASTM C 1202 [26]. This test was conducted on saturated 50 mm thick concrete slice of 100 mm diameter extracted from the concrete specimen (of diameter =100 mm and length = 200 mm) during each cycle of testing. A potential difference of 60V DC was maintained across the ends of the specimen, one end (which is exposed to 5 bars of hydraulic pressure) immersed in 3.0% NaCl solution and the other end in 0.3M NaOH solution. Samples undergoing RCPT as per ASTM C1202 have been shown in Figure 3.

Fig. 3 Specimen being tested as per ASTM C1202 (RCPT test)

4.6.2. Air Permeability Test

This test was conducted on concrete slab (300 mm × 300 mm × 100 mm) at 28 days. The two-chamber vacuum cell (Figure 4) is sealed on concrete surface using pair of concentric soft rings, creating two separate chambers. After that, between 35 and 60 seconds, valve 2 is closed and inner chamber is isolated from pump. The air in pores of the material flows into inner chamber through cover concrete, raising its pressure Pi. The rate of pressure rise ΔPi with time (measurement begins at t_0 = 60 seconds) is directly related to coefficient of air permeability (K_T) of the cover concrete.

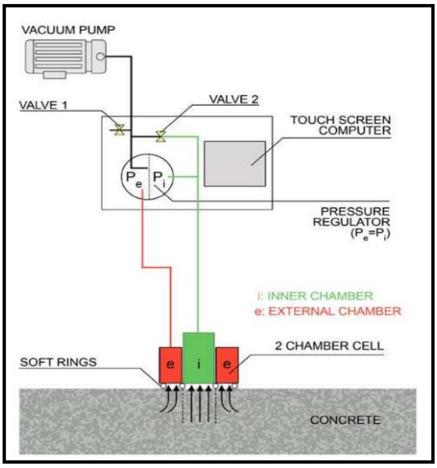

Fig. 4 Sketch of air-permeability test

4.6. Performance of Concrete Exposed to High Temperature

Concrete specimens made with PPC without micro fibres and with micro fibres were cast for evaluation of performance of concrete exposed to high temperature. Concrete cylinders (with dimensions of diameter 100 mm and length 200 mm) were exposed to 200 ^{0}C and 600 ^{0}C for the duration of 1 hour as shown in Figure 5 and were tested for compressive strength as shown in Figure 6 and 7. Specimen subjected to elevated temperature were also evaluated for flexural and split tensile strength. For flexural test concrete beam with (100 mm × 100 mm × 500mm) were cast. Whereas, for split tensile strength, concrete cylinder (diameter of 100 mm and height of 200 mm) were cast. Specimens were heated in an electrical furnace while maintaining a rate of heating as 50C/min till the desired temperature is achieved and further the specimen was exposed to that desired temperature for 1 hour.

Fig. 5 Concrete specimen in furnace for fire exposure

Fig. 6 Concrete specimen made with PPC-0 undergoing compressive strength testing

Fig. 7 Concrete specimen made with P-MF-0.20 undergoing compressive strength testing

5. Results and Discussion

5.1 Characterization of PPC Samples Containing Micro Fibre

All the four PPC samples, control as well as PPC containing micro fibre (i.e. P-MF-0.20, P-MF-0.40 and P-MF-1.0) were analyzed for various chemical properties. The results of chemical analysis (Table 1) of PPC samples showed their conformance to the chemical requirements of PPC as specified in Indian standard IS 1489 (Pt-1):2015 with comfortable margin and comparable to control cement.

Table 1. Chemical analysis (% by mass) of PPC samples

Sample	LOI*	MgO	SO_3	IR#	Cl
PPC-0	1.08	1.88	2.33	31.59	0.019
P-MF-0.20	1.70	1.82	2.35	31.57	0.017
P-MF-0.40	1.61	1.85	2.38	31.80	0.018
P-MF-1.0	1.69	1.87	2.33	32.26	0.020
Upper Limit as per IS 1489 (Pt-1):2015	5.0	6.0	3.50	-	0.10

*LOI- Loss on Ignition, #IR- Insoluble residue

The Portland Pozzolana cement samples were evaluated for their physical properties. The results have been tabulated in Table 2. Normal consistency (i.e. water requirement) of PPC containing glass microfibre was observed to be comparable with PPC without micro fibre.

The values of initial and final setting times of PPC with micro fibre were found to be in the range of 115-155 and 185-215 minutes as compared to control PPC sample indicating similar setting times of resultant cements on addition of micro fibre. The SO_3 contents in control and cement samples containing micro fibre were also in comparable range.

The values of 3, 7 and 28 days' compressive strength of PPC samples prepared with 0.2 % and 0.40% micro fibre were observed to be higher in comparison to control PPC. However, as we increase the micro fibre content to 1 %, compressive strength was found to be lower than control PPC at all the 3 ages. Compressive strength of PPC containing 0.2% micro fibre was found to be highest among all the 4 PPCs. All the PPCs were comfortably meeting the strength requirements suggested by IS 1489 (Pt-1):2015. Since, diameter of glass micro fibres are in microns, the fine strands of glass micro fibre have a tendency to agglomerate and stick together while mixing with PPC in laboratory ball mill, when the dosage of micro fibres goes beyond 0.2% by weight of cement. Those agglomerated strands might create inhomogeneity in cement mortar which leads to weaker pockets and might result in lower compressive strength of cement mortar sample.

PPC samples were tested for dimensional stability (soundness) as per the method given in Indian standard IS: 4031(3)-1988). The Le-chatelier's and autoclave expansions in PPC samples prepared in both sets were found to be in the range of 1.0 to 2.0 mm and 0.04-0.06% respectively and fulfilled the criterion specified for soundness.

Table 2. Physical properties of PPC samples

Parameter		PPC-0	P-MF-0.20	P-MF-0.40	P-MF-1.0	Limits as per IS 1489 (Pt-1):2015
Normal consistency (%)		33.0	33.2	32.4	34.4	-
Specific gravity		2.81	2.88	2.87	2.94	-
Soundness	Le. Chat. (mm)	1.0	1.0	2.0	1.0	≤ 10
	Autoclave (%)	0.04	0.04	0.05	0.06	≤ 0.8
Fineness (m^2/kg)		317	317	317	319	≥ 300
Setting Time	Initial (minutes)	150	155	135	115	≥ 30
	Final (minutes)	220	215	205	185	≤ 600
Compressive Strength	3 days (MPa)	23.5	32.0	30.0	22.5	≥ 16
	7 days (MPa)	35.0	43.0	40.0	32.0	≥ 22
	28 days (MPa)	47.5	54.0	51.5	44.0	≥ 33

5.2 Characterization of Glass Micro Fibre

Length and diameter of glass fibre was investigated using scanning electron microscope (SEM) as shown below in Figure 8 and 9.

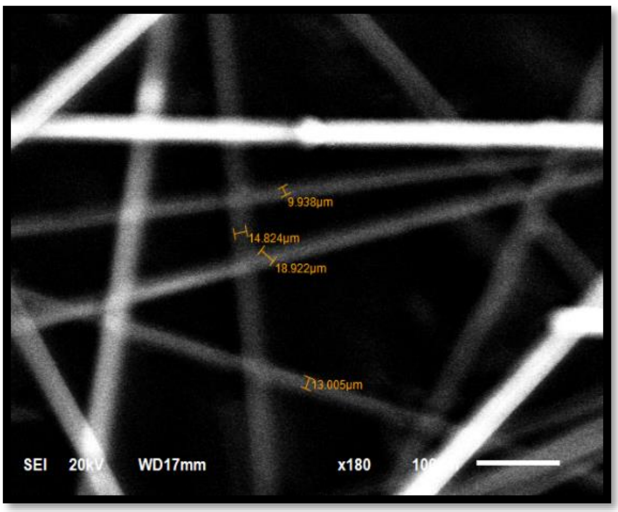

Fig. 8 Diameter of glass microfibre using SEM

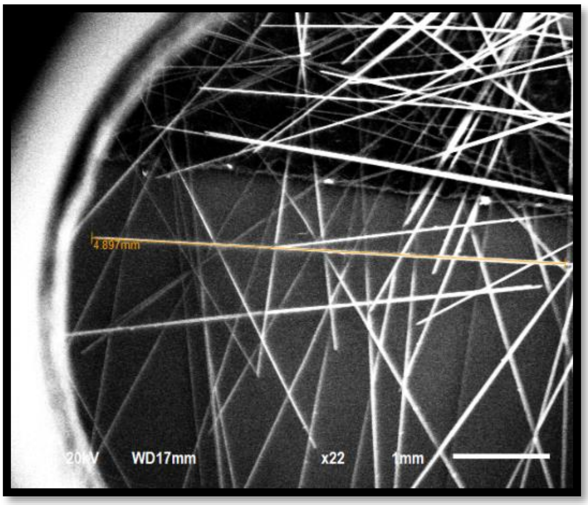

Fig. 9 Length of glass microfibre using SEM

Average diameter of micro fibre using SEM was observed to be around 14.17 micron and average length was observed to be around 4 mm. Apart from length and diameter all the other properties of glass micro fibre has been provided in Table 3.

Table 3. Physical properties of glass micro fibre

Specifications	Values
Elongation	2.4%
Specific gravity	2.68
Melting point	>1000^{o}C
Initial modulus	72000 MPa
UV Stability	Very good
Alkaline resistance stability	Excellent
Moisture regain	< 0.2%
Electrical Conductivity	Very Low
LOI	0.57%
Density	2685 Kg/m^3
Tensile strength	1714 MPa

5.3. Characterization of Aggregates

The physical properties of coarse aggregate and fine aggregates used for study have been tabulated in Table 4. Test results indicate that both coarse and fine aggregate used for preparation of concrete mixes in this study meet the various requirements of IS 383: 2016.

Table 4. Physical Properties and sieve analysis (gradation) of coarse and fine aggregates

Parameter		Coarse aggregates 20 mm	Coarse aggregates 10 mm	Fine Aggregate
Specific gravity		2.83	2.83	2.73
Water absorption (%)		0.3	0.3	1.10
Sieve Analysis Cumulative Percentage Passing (%)	20mm	98	100	-
	10 mm	1	68	100
	4.75 mm	0	2	100
	2.36 mm	0	0	87
	1.18 mm	0	0	63
	600 μ	0	0	49
	300 μ	0	0	39
	150 μ	0	0	27
	Pan	0	0	0
Abrasion Value		19	-	-
Crushing Value		19	-	-
Impact Value		13	-	-
Flakiness %		29	-	-
Elongation %		25	-	-

5.4. Mix Details of Concrete Mixes Prepared Using PPC With and Without Microfibre

Three concrete mixes were prepared using control PPC and PPC containing 0.20% and 0.40% micro fibre at w/c of 0.50 and cementitious content of 340 kg/m^3 for studying engineering properties of fresh and hardened concrete. Dosage of Naphthalene based super plasticizer (chemical admixture) was varied for individual mixes to keep initial slump of concrete in the range of 100 to 150 mm. Details of concrete mixes are tabulated in Table 5.

Table 5. Details of concrete mixes

Mix	Cement (Kg/m^3)	Water (Kg/m^3)	Fine Aggregates (Kg/m^3)	Coarse Aggregates (10 mm) (Kg/m^3)	Coarse Aggregates (20mm) (Kg/m^3)	Admixture (%)
PPC-0	340	170	645	520	779	1.3
P-MF-0.20	340	170	648	522	783	1.2
P-MF-0.40	340	170	648	522	782	1.2

5.5. Engineering Properties of Fresh Concrete

The test results of slump test, air content and plastic shrinkage test are given in Table 6. The slump and air content of concrete mixes prepared using PPCs containing micro fibre were similar and comparable to the mixes prepared using control PPC. In case of crack width measurement in plastic shrinkage test, average of 20 cracks measurements taken across the section (as shown in Figure 10 and Figure 11) were reported. Reduction in cracks due to plastic shrinkage of concrete was observed on addition of 0.20% and 0.40 % micro fibre in PPC by weight of cement (Figure 3). The inclusion of glass microfibers in PPC reduced and controlled the cracking occurring due to plastic shrinkage and further delayed the appearance of first crack, because inclusion of the glass microfibers increased the tensile strain capacity of experimental concrete and restricted the growth of cracks occurring due to plastic shrinkage.

Table 6. Fresh concrete properties

Mix ID	Initial Slump of concrete (mm)	Air Content (%)	Bleeding	Plastic Shrinkage (Avg. Crack Width)
PPC-0	120	2.90	Zero	1.0275 mm
P-MF-0.20	110	1.90	Zero	0.615 mm
P-MF-0.40	130	3.00	Zero	0.315 mm

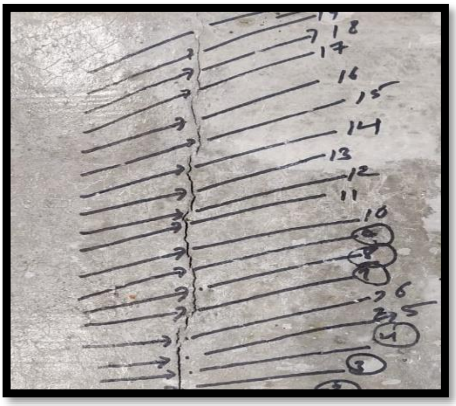

Fig. 10 Plastic shrinkage crack in concrete made with PPC-0

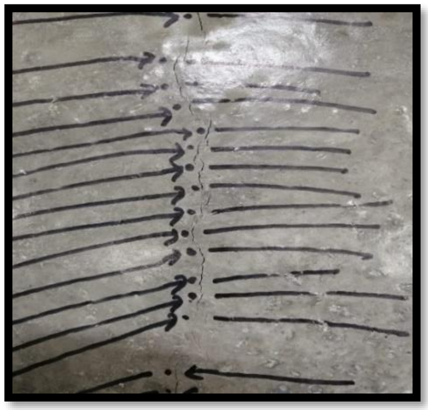

Fig. 11 Plastic shrinkage crack in concrete made with P-MF-0.20

5.6. Engineering Properties of Hardened Concrete

For engineering properties of hardened concrete compressive strength, flexural strength, split tensile strength, Modulus of Elasticity and drying Shrinkage were evaluated. The test results are tabulated in Table 7.

Table 7: Engineering properties of Hardened Concrete

Mix ID	Compressive Strength, MPa		Flexural Strength, MPa		Split Tensile Strength, MPa		Modulus of Elasticity MPa	Drying Shrinkage (%)
	7 Day	28 Day	7 Day	28 Day	7 Day	28 Day	28 Days	28 Days
PPC-0	25.65	34.79	4.03	5.60	1.89	3.14	33374	0.0202
P-MF-0.20	21.81	32.45	3.17	6.32	1.57	2.75	30908	0.0162
P-MF-0.40	23.47	32.33	3.50	6.54	1.80	2.74	30180	0.0177

Concrete mixes prepared using control PPC and PPC containing 0.20% and 0.40% micro fibre showed comparable compressive strength at 28 days. Whereas, an improvement was observed in flexural strength of concrete at 28 days on introduction of micro fibre because inclusion of the glass microfibers increased the tensile strain capacity of experimental concrete and restricted the growth of cracks. Marginal reduction in split tensile strength and modulus of elasticity values of concrete was observed on introduction of micro fibre in concrete which indicates that inclusion of glass microfibers enhances toughness and strain hardening but not the tensile property significantly. Drying shrinkage of concrete got slightly reduced due addition of micro fibre in PPC because addition of fibers in cement concrete matrix bridges shrinkage and restrains them from opening. Glass microfibers delayed the evaporation of the free and absorbed water, favoring the hydration of cement

5.7 Microstructure Study of Concrete Using SEM

The microstructure of hardened concrete samples was analysed using a scanning electron microscope (SEM). Microstructure of concrete prepared using PPC without and with glass microfibre have been shown below in Figure 12 and Figure 13.

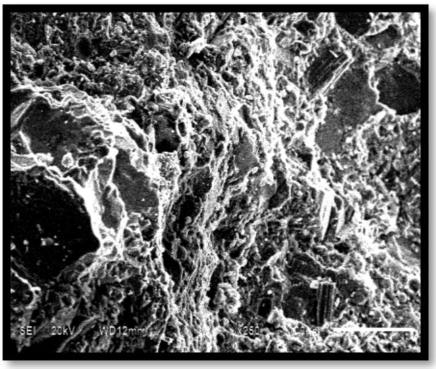

Fig. 12 Microstructure of concrete prepared using PPC without glass microfibre

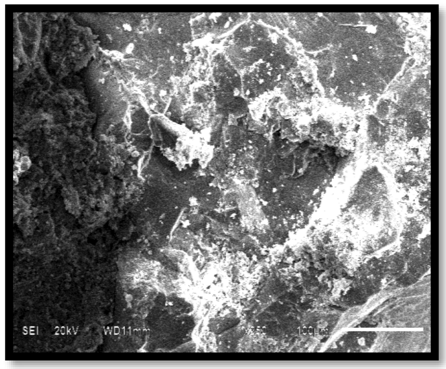

Fig. 13 Microstructure of concrete prepared using PPC containing glass microfibre

Since, glass microfibre added in PPC will not interact chemically with any constituent of PPC and are chemically inert in nature, hydration products and microstructure of concrete prepared with PPC having micro fibre and concrete prepared using PPC-0 was observed to be almost similar.

5.8. Durability Properties of Hardened Concrete

5.8.1 Rapid Chloride Penetration Test (RCPT)

The total charge passed (in coulombs) was determined and is related to the chloride ion penetrability class according to the criteria given in ASTM C1202. The total charge passed (in coulombs) through samples of various grades at the age of 28 days has been given in Table 8.

Table 8. RCPT results of concrete mixes at 28 days

Mix ID	Charge Passed (Coulombs)	Permeability Class as per ASTM C1202
PPC-0	1287.33	Low
P-MF-0.20	1496.33	Low
P-MF-0.40	2427.33	Moderate

The RCPT results at 28 days (as per Table 8) indicates that charge passed through concrete specimen prepared using control PPC and PPC containing 0.20% micro fibre by weight of cement are comparable and thus concrete in both of cases fall under same permeability class i.e. low. Inclusion of micro fibre beyond 0.20% deteriorates the performance of concrete against chloride penetration.

5.8.2. Air Permeability Test

Classification of quality of concrete based on the value of K_T is provided in Table 9. The air permeability results for various grades of concrete have been tabulated in Table 10.

Table 9. Classification of quality of concrete according to K_T

Classification of quality of concrete	K_T measured at 28 days (10^{-16} m^2)
Very Good	$K_T< 0.01$
Good	$0.01 < K_T< 0.10$
Normal	$0.1 < K_T< 1.0$
Bad	$1.0 < K_T< 10$
Very Bad	$K_T> 10$

Table 10. Coefficient of air permeability results

Mix ID	K_T measured at 28 days (10^{-16} m^2)	Quality of Concrete
PPC-0	0.195	Normal
P-MF-0.20	0.017	Good
P-MF-0.40	0.035	Good

As mentioned in Table 9, concrete can be classified into different categories on the basis of coefficient of air permeability values. The results of Coefficient of Air permeability at 28 days (as per Table 10) clearly suggests that there is a clear and significant reduction in coefficient of air permeability (K_T) values as we introduce micro fibres (0.2% and 0.4% by weight of cement) in PPC and hence quality of concrete improves from normal to good. This is because microfibers decrease the porosity and the capillary absorption, and increase the resistance to the penetration. The decrease in air permeability of concrete is due to the filling effect of the microfibers. This effect is due to replacement of the space left by the evaporation of the water by fibers, causing a further increase in density. The values of K_T for concrete prepared using 0.2 % and 0.4% micro fibre are very much comparable. However, the least value of K_T was observed in case of concrete prepared using PPC containing 0.20% micro fibre by weight of cement.

5.9. Performance of concrete Exposed to High Temperature

Concrete specimens prepared using PPC with and without glass micro fibres were exposed to elevated temperatures as discussed in methodology and were further tested for compressive strength Compressive strength results at room temperature and after subjecting to elevated temperature have been tabulated in Table 11.

Table 11. Compressive strength results in fire study

Sample	Room Temperature	200^0C	600^0C
PPC 0	27.14 MPa	21.32 MPa	15.98 MPa
P-MF 0.20	27.92 MPa	24.34 MPa	15.62 MPa
P-MF 0.40	26.93 MPa	22.94 MPa	10.43 MPa

From the experimental results, improvement in reduction in compressive strength is observed for 200^0C while no improvement is observed for the 600^0C exposure. Significant reduction (41% and 54.51%) in strength was observed when concrete is exposed to 600^0C. However, there is slight reduction in compressive strength upon addition of fibers at room temperature itself. Therefore, glass micro fibers were found to be useful only up to 200^0C but the reduction in strength upon addition of fibers should be considered while the design mix of the concrete.

Similarly, no significant improvement was observed in case of residual split and flexural strength after exposure to elevated temperatures. There is decrease in the split and flexural strength upon exposure to higher temperatures and no improvement was observed upon addition of glass microfiber in PPC cement in residual strengths. The test results of split tensile strength and flexural strength are given in Table 12 and Table 13 respectively.

Table 12. Split tensile strength results in fire study

Sample	Room Temperature	200^0C	600^0C
PPC 0	3.76 MPa	3.60 MPa	Cracked
P-MF 0.20	3.11 MPa	2.99 MPa	1.65 MPa
P-MF 0.40	3.39 MPa	3.17 MPa	1.40 MPa

Table 13. Flexural strength results in fire study

Sample	Room Temperature	200^0C	600^0C
PPC 0	5.60 MPa	4.12 MPa	2.86 MPa
P-MF 0.20	6.32 MPa	4.53 MPa	0.88 MPa
P-MF 0.40	6.54 MPa	3.96 MPa	Cracked

6. Conclusion

Based on the study conducted and literature reviewed, it can be concluded that:

In case of mortar, dosage of 0.20% of glass microfibre in PPC was observed to be optimum as it leads to highest compressive strength at all the ages among all the PPCs. However, corresponding improvement in concrete was not observed.

Reduction in cracks due to plastic shrinkage of concrete was observed on addition of 0.20% and 0.40% micro fibre in PPC by weight of cement. The inclusion of glass microfibers in PPC reduced and controlled the cracking occurring due to plastic shrinkage and further delayed the appearance of first crack, because inclusion of the glass microfibers increased the tensile strain capacity of experimental concrete and restricted the growth of cracks occurring due to plastic shrinkage. All the other physical and chemical parameters of PPC containing 0.20% micro fibre by weight of cement were found to be comparable with control PPC. Coefficient of air permeability (K_T) values was observed to be significantly lower for concrete containing glass micro fibres in comparison to concrete without glass micro fibres. The decrease in air permeability of concrete is due to the filling effect of the microfibers. This effect is due to replacement of the space left by the evaporation of the water by fibers, causing a further increase in density. All the other fresh, hardened and durability properties of concrete mixes prepared using PPC containing 0.20% micro fibre by weight of cement were found to be comparable with control mixes. Improvement was observed in flexural strength of concrete at 28 days on introduction of micro fibre. In addition to plastic shrinkage, drying shrinkage of concrete made with PPC containing glass micro fibre was observed to be lower in comparison to concrete made with PPC without glass micro fibre. Drying shrinkage of concrete got slightly reduced due addition of micro fibre in PPC because addition of fibers in cement concrete matrix bridges shrinkage and restrains them from opening. Glass microfibers delayed the evaporation of the free and absorbed water, favoring the hydration of cement

From the experimental results of fire exposure of concrete, less reduction in compressive strength was observed for concrete containing glass micro fibre for exposure at 200^0C in comparison to concrete without glass micro fibre. While no such improvement was observed for exposure at 600^0C exposure. No significant improvement was observed in case of residual split and flexural strength after exposure to elevated temperatures.

Study shows that addition of glass micro fibres at 0.2 % by weight of cement in Portland Pozzolana Cement leads to improved performance in terms of compressive strength of cement at all ages. However, no significant improvement in the mechanical properties of concrete made with PPC having glass micro fibre (0.2 % Weight of cement) at normal and elevated temperature was observed. However, concrete containing glass microfibre showed improved resistance against crack formation occurring due to plastic shrinkage. Concrete containing glass microfibre showed better performance in terms of drying shrinkage and air permeability in comparison to concrete without glass microfibre.

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