

Influence of Fibers and Fly Ash on Mechanical Properties of Concrete

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Abstract The Present study was carried out to evaluate the influence of addition of Fibres and Class 'C' Flyash on the mechanical properties of concrete. Fibre Reinforced Concrete (FRC) is very useful in extreme climate where shrinkage of concrete causes cracks. The Fibre Reinforced Flyash concrete (FRFAC) has been successfully used to minimize cavitations / damages in hydraulics structures. The FRC with and without Fly ash was tested with the fraction of volume of the steel Fibre in concrete which varied from 0.0 to 1.0%. For determining, the compressive strength & permeability cubes of 150 mm size were prepared. Nine cubes of each series were prepared; out of nine, three were used for determining the strength & permeability of cracked & un-cracked concrete. The formation of additional calcium silicate hydrates in the hydrated cement matrix because of the addition of fly ash in FRFAC results in its improved characteristics. The initial tangent modulus of FRC and FRFAC is found to be independent of the quantity of Fibers. The experimental investigation shows that the increase in the Fibre content increases the compressive strength, crushing strain and Poisson's Ratio of FRC and FRFAC. While increasing the Fibre content, the permeability of concrete reduced. The mode of cracking has been discussed.

Keywords: FRC, steel fiber, fly ash, permeability

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1. Introduction

The extensive investigation has been carried out on mixing of different types of fibers to the conventional concrete. The addition of steel fibers of suitable size, shape and aspect ratio to a properly designed concrete mix improves its resistance to tensile stress and modifies the brittle behaviour considerably and reduces shrinkage and temperature cracks. Fiber Reinforced Concrete (FRC) is very useful in extreme climates where shrinkage of concrete causes cracks. It is increasingly being used for precast elements, airport runways and tunnel lining. While addition of fly ash in FRC improves its compressive strength and reduces permeability at same workability. The fibers and fly ash are added for improving its performance against creep, wear, fracture and decrease in the permeability. The Fiber Reinforced Fly Ash Concrete (FRFAC) has been successfully used to minimize cavitation / erosion damages in hydraulic structures such as sluiceways; navigation docks and bridge piers where high velocity flows are encountered. It is also rapidly gaining acceptance as suitable material for repairing, rehabilitation and renovation of concrete structures. Topçu and Canbaz [1], demonstrated through experiments that

the addition of fibers provide better performance for concrete, while fly ash in the mixture may adjust the workability and strength losses caused by fibers, and improve strength gain. The results are based on experimental investigations in which concrete was produced with three different replacement ratios of fly ash and three different types of steel and polypropylene fibers. Sahmaran M and Yaman [2] showed through experimental study that high volume of coarse fly ash can be used to produce fiber reinforced Self Compacting Concrete (SCC), but there is some reduction in the concrete strength because of the use of high-volume of coarse fly ash. The experimental study involved concrete mixes with 50% replacement of cement by fly ash and two different types of steel fibers were used in combination, keeping the total fiber content constant at 60 kg/ m³. A polycarboxylic-based superplasticizer was used in combination with a viscosity modifying admixture. Sukumar B. et al. [3] studied the rate of gain in strength at different periods of curing varying from 12 h to 28 days for various grades of different SCC mixes and developed suitable relations for compressive strength and split tensile strength for different grades of SCC mixes. Khunthongkeaw J. et al. [4] developed a mathematical approach to predict the carbonation depth in fly ash concrete under natural environment based on the accelerated tests. They showed

that for the same fly ash content, specimens of high-CaO fly ash show a better carbonation resistance than those of low CaO fly ash. Chindaprasirt P. et al. [5] used Ground Palm Oil fuel Ash (GPOA) and Ground Rice husk Bark Ash (GRBA), which are by-products from electricity generating power plants and disposed as wastes in landfills, as a partial cement replacement. Their experiments indicate that both of GPOA and GRBA can be used as new pozzolanic materials to concrete with an acceptable strength as well as permeability. Guneyisi E. et al. [6] studied the effect of initial curing conditions on the chloride ingress characteristics of concretes made with plain and four different blended cements. The results indicated that the initial curing condition had pronounced effects on the related properties: in particular, the most prominent effects were observed on blended cement concretes, which performed extremely well when initially cured in wet conditions. Inadequate or poor initial curing

practice resulted in remarkably lower chloride penetration resistance for both plain and especially blended cement concretes. Ganesan K. et al. [7] studied the influence of Rice Husk Ash (RHA). Test results obtained in this study indicate that up to 30% of RHA could be advantageously blended with cement without adversely affecting the strength and permeability properties of concrete. Another interesting observation emanating from this study is the linear relationship that exists among water permeability, chloride penetration and chloride diffusion. The present study was carried out to evaluate the influence of addition of Class 'C' flyash and steel fibers on the mechanical properties of concrete. The concrete mixture without fly ash was proportioned to have 28-day strength of 20 MPa. Concrete mixtures were also proportioned to have cement replacement with fly ash in the range of 10% by weight. For each concrete mixture, stress-strain characteristics and water permeability were determined.

Table 1. Physical properties of materials*

S. No.	Materials	Physical Properties	Value
1.	Cement (43 grade OPC)	Normal consistency	27%
		Initial Setting Time	28 min
		Final Setting Time	322 min
		Compressive Strength (1:3 cement sand mortar)	20.0 MPa (3 days)
			28.5 MPa (7 days)
Tensile Strength (1:3 cement sand mortar)	1.95 MPa (3 days) 2.35 MPa (7 days)		
2.	Fly Ash	Specific Gravity	1.85 at 25°C
		Optimum Moisture Content (Standard Proctor Test)	18%
		Maximum Dry Density	1.28 g/cc
3.	Fine Aggregate (Coarse sand)	Specific Gravity	2.61
		Water Absorption (30 min)	0.44%
		Fineness Modulus	2.87
		Silt Content	2.46%
4.	Coarse Aggregate (MSA = 10 mm)	Specific Gravity	2.64
		Water Absorption (30 min)	0.40%
		Fineness Modulus	3.578
5.	Coarse Aggregate (MSA = 20 mm)	Specific Gravity	2.63
		Water Absorption (30 min)	0.39%
		Fineness Modulus	3.750
6.	Steel Fiber	Diameter	0.495 mm
		Aspect Ratio (Length/Diameter)	54.7
		Ultimate Tensile Strength	1920 MPa

* MSA = Maximum Size of Aggregate

Table 2. Elemental analysis of fly ash along with their range for different materials

Components	Range of percentage of component for different materials				Percentage of Fly Ash Used
	Bituminous	Sub-Bituminous	Lignite	Fly Ash Class C	
SiO ₂	20-60	40-60	15-45	46-60	52.50
Al ₂ O ₃	5-35	20-30	10-25	21-28	20.95
Fe ₂ O ₃	10-40	4-10	4-15	05-09	8.88
CaO	1-12	5-30	15-40	0.5-6	5.77
MgO	0-5	1-6	3-10	0.2-4	3.65
SO ₃	0-4	0-2	0-10	0-0.4	0.21
Na ₂ O	0-4	0-2	0-6	0-0.3	0.19
K ₂ O	0-3	0-4	0-4	0-0.2	0.11
LOI	0-15	0-3	0-5	0-0.2	0.14

2. Experimental program

2.1. Materials Used

The fly ash used in the present study was the portion of the ash collected from electrostatic precipitators of Dadri thermal power station, Dadri (U.P.), India. Crushed stone aggregates of 20 mm and 10 mm maximum size were used

as coarse aggregates and locally available coarse sand was used as fine aggregate. The cement used was Ordinary Portland Cement (OPC) of 43 grade. The physical properties of materials are given in Table 1 and the results of elemental analysis of fly ash along with their range for different materials are given in Table 2.

2.1.1. Preparation of Specimens

For determining the compressive strength, cubes of 150 mm size were prepared. The concrete mix was designed to get the compressive strength of 20 MPa. The water-cement ratio of 0.5 was adopted corresponding to the target mean strength. The mix proportion for each test series is given Table 3. Nine cubes of each series were prepared – three each were used for determining compressive strength, permeability of uncracked and cracked concrete. The material was weighed dry and placed on a level platform for mixing, fibers were sprinkled gently and mixed dry by using trowel and then the calculated quantity of water was added to the dry mix. Every care was taken to prevent agglomeration of fibers and to ensure their uniform distribution as far as possible. The concrete was poured in three equal layers in the

moulds of the cube. Care was taken to ensure that the concrete was properly placed and compacted. The specimens were immersed for curing in potable water tank.

Figure 7 to Figure 9 show some of the empty moulds, steel fibers and some of the compacted moulds respectively.

Table 3. Mix Proportion of Different Cubes*

Mix	Cube Designation	Mix Proportion					Fiber content (%)
		Cement (kg/m^3)	FA (kg/m^3)	CA		F-A (kg/m^3)	
				10 mm (kg/m^3)	20 mm (kg/m^3)		
M-20	0.00 FRC	403.2	672.0	470.0	873.6	-	0.00
M-20	0.25 FRC	402.2	670.0	469.0	871.4	-	0.25
M-20	0.50 FRC	401.2	668.6	468.0	869.2	-	0.50
M-20	0.75 FRC	400.2	666.9	466.8	867.0	-	0.75
M-20	1.00 FRC	399.2	665.2	465.7	864.8	-	1.00
M-20	0.00 FRFAC	362.9	671.4	470.0	873.7	40	0.00
M-20	0.25 FRFAC	361.9	670.0	469.0	871.4	40	0.25
M-20	0.50 FRFAC	361.1	668.6	468.0	869.2	40	0.50
M-20	0.75 FRFAC	360.2	666.9	466.8	867.0	40	0.75
M-20	1.00 FRFAC	359.2	665.2	465.7	864.8	40	1.00

*FA = Fine Aggregate, CA = Coarse Aggregate, F-A = Fly Ash, CC = Cement Concrete; FRC = Fiber Reinforced Concrete; FRFAC = Fiber Reinforced Fly Ash Concrete.

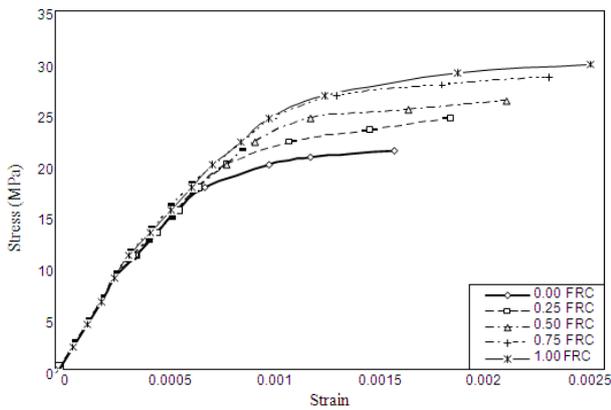


Figure 1. Stress-strain curves of FRC

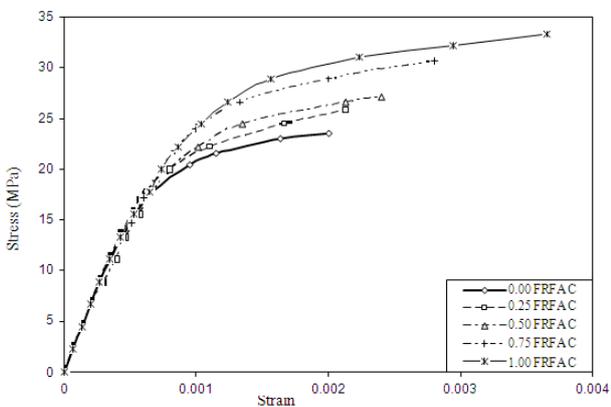


Figure 2. Stress-strain curves of FRFAC

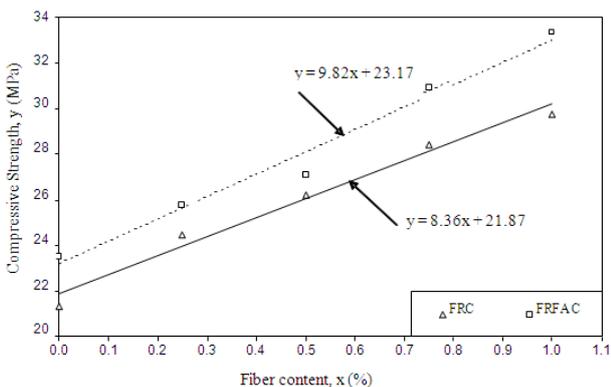


Figure 3. Variation of compressive strength with fiber content for FRC and FRFAC

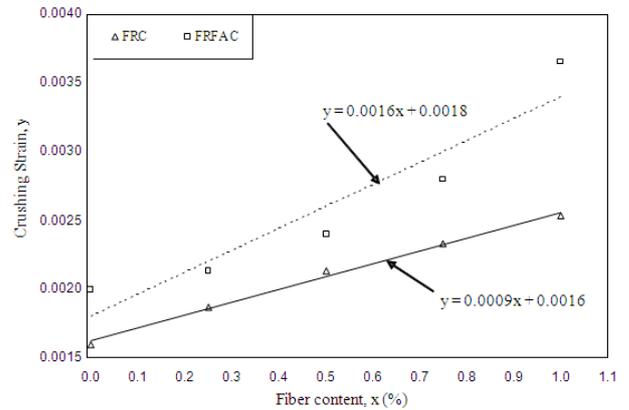


Figure 4. Variation of crushing strain with fiber content for FRC and FRFAC

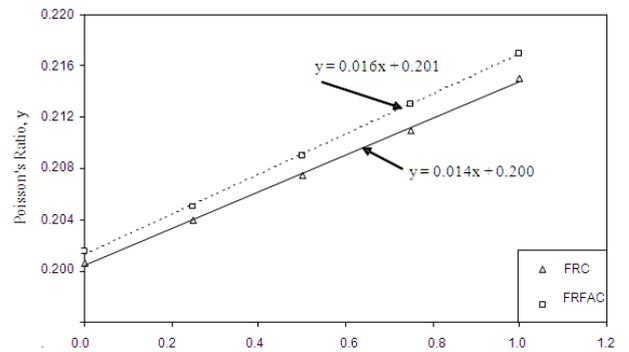


Figure 5. Variation of Poisson's ratio with fiber content for FRC and FRFAC

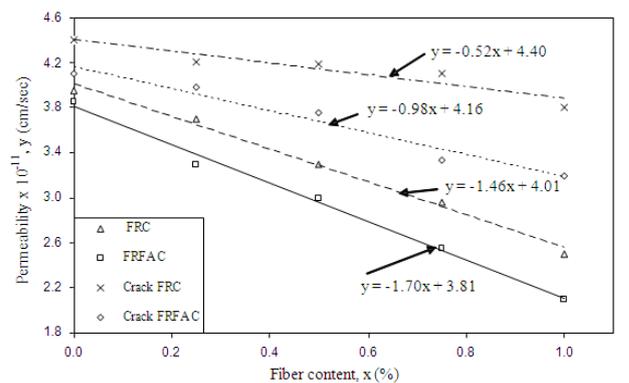


Figure 6. Variation of permeability with fiber content for uncracked and cracked FRC and FRFAC



Figure 7. Cube moulds



Figure 8. Steel fiber



Figure 9. Prepared cubes



Figure 10. A cube being tested under compression

2.1.2. Compression Testing of Cubes

The cubes were tested in compression testing machine at 28 days after water curing of specimen for 28 days. The load and corresponding deformations were measured

during the test. One of the specimens under test is shown in Figure 10. The stress-strain curves of different test series of FRC and FRFAC are plotted in Figure 1 and Figure 2 respectively. It is to be noted here that each stress-strain curve is the average of three test results. The modulus of elasticity has been taken as the initial tangent modulus, which has been determined from the stress-strain curves. The variation of compressive strength, crushing strain and Poisson's ratio with the variation in the percentage of fibers is plotted in Figure 3, Figure 4. It is observed from Figure 1 and Figure 2 that all of the stress-strain curves are parabolic with almost linear portion upto $0.3f_c$, where, f_c is the uniaxial compressive strength. The initial tangent modulus of all specimens is almost independent of the quantity of fibers (Figure 1, Figure 2) – its value is 32 GPa for both FRC and FRFAC. The compressive strength of FRC and FRFAC increases almost linearly with increase in the percentage of fibers (Figure 3). The equation of the models is written in the figure and reported in Table 4. The increase in the quantity of fibers from 0.0 to 1.0% results in approximately 39.6% and 41.8% increase in the compressive strength of FRC and FRFAC respectively. The percentage increase in the compressive strength of concrete with increase in the percentage of fiber in concrete with and without fly ash being almost same, the role of fibers in both of the mixes is almost the same. It is observed that the compressive strength of FRFAC is 6 to 9% more than that of FRC. The increase in compressive strength due to the addition of fly ash is because of the formation of additional calcium silicate hydrates in the hydrated cement matrix. The crushing strain of different test series of concrete is plotted in Figure 4. It is observed that the crushing strain increases linearly with the increase in the quantity of fibers in FRC as well as FRFAC. The equation of the models is written in the figure and reported in Table 4. The increase in crushing strain of FRC and FRFAC with the increase in the quantity of fibers from 0.0 to 1.0% is 58.3 and 82.7% respectively which indicates that the addition of fibers introduces ductility in concrete. The Poisson's ratio of concrete has been calculated from the measurement of lateral strain. The measurements of lateral strain were taken upto the load just prior to the first crack load. The variation of Poisson's ratio of different specimens with the percentage of fibers is plotted in Figure 5. It is observed from the figure that the Poisson's ratio increases almost linearly with increase in the percentage of fibers. As the percentage of fibers increases from 0% to 1%, the value of Poisson's ratio increases nominally from 0.2006 to 0.2150 for FRC and 0.2015 to 0.2170 for FRFAC. The equation of the models is written in the figure and reported in Table 4. However, the value of Poisson's ratio for practical purposes may be taken as 0.2, independent of fiber content, for FRC as well as FRFAC. The crack patterns observed in the failure of cubes are shown in Figure 11. Most of the cracks are almost along the line of action of the load, which indicates that the failure is mainly by lateral tension and shear failure of specimen close to the platens is observed in some of the specimen. The cracks observed are not straight and have branches, which is due to the presence of fibers. The first visual crack observed by naked eye is at $0.30 f_c$ in FRC and FRFAC.

Table 4. Mathematical models for crushing strength, crushing strain, modulus of elasticity, Poisson's ratio and permeability

S.No	Independent variable, y	Dependent variable, x	Equation of model	
			FRC	FRFAC
1.	Compressive strength (MPa)	Fiber content in percentage	$y=8.36x+21.87$	$y=9.82x+23.17$
2.	Crushing strain	Fiber content in percentage	$y=0.0009x+0.0016$	$y=0.0016x+0.0018$
3.	Poisson's ratio	Fiber content in percentage	$y=0.014x+0.200$	$y=0.015x+0.201$
4.	Initial tangent modulus (GPa)	Fiber content in percentage	$y=32$	$y=32$
5.	permeability	Fiber content in percentage	Uncracked: $y=-1.46x+4.01$	Uncracked: $y=-1.70x+3.81$
			Cracked: $y=-0.52x+4.40$	Cracked: $y=-0.98x+4.16$



Figure 11. Crack patterns in cubes tested under direct compression

2.1.3. Permeability Test

2.1.3.1. Test Method

The three-cell water permeability apparatus was used for determining the permeability of concrete. The concrete specimens were tested for permeability at the age of 28 days. The specimens were cube of 150 mm size. The material was compacted by tamping rod. The collar was then removed and the mould was struck off level with a straight-edge using a sawing motion without further trovelling or finishing. The specimen was water cured for 28 days. The specimen was surface dried and the dimensions measured. It was then centred in the cell, with the lower end resting on the ledge. The space between the specimen and the cell was tightly caulked to a depth of about 10 mm using cotton soaked in molten sealing compound. The rest of the space was carefully filled with the molten sealing compound, leveled with the top of the specimen. The sealing compound used was the mixture of bees-wax and rosin, applied smoking hot. Their proportions were chosen by trial. The water-tightness of the seal was tested by bolting on the top cover plate, inverting the cell and applying an air pressure of 0.1 to 0.2 Mpa from below. A little water was poured on the exposed face of the specimen to detect any leaks through the cell. In case of leaks, the specimen was taken out and resealed. With the system completely filled with water, the cell pressure was maintained at 0.75 MPa throughout the test. The quantity of water percolating through the

specimen and the gauge-glass readings were recorded at periodic intervals. In the beginning, the rate of water intake was larger than the rate of outflow. As the steady state of flow approached, the two rates became equal. With further passage of time, both the inflow and outflow registered a gradual drop. Permeability test was continued for 100 hours after the steady state of flow was reached and the outflow was considered as average of all the outflows measured during this period of 100 hours.

2.1.4. Test Results

The permeability of concrete has been plotted in Figure 6 against the fiber content for FRC and FRFAC. The permeability tests were also conducted on cracked specimen of FRC and FRFAC and these results are plotted in Figure 6. The cracked specimens are the specimen tested for permeability after the development of first crack when compressed in compression testing machine. It is observed from the figure that the increase in the fiber content reduces the permeability of concrete and the addition of fly ash in FRC also reduces its permeability. The fly ash, which is alumino silicate, reacts with Ca(OH) 2 to form additional calcium silicate hydrates in the hydrated cement matrix. These additional hydrates increase the density of the matrix and refine the pore structure by improving the particle packing of cement paste thus reducing the permeability of the concrete. The increase in fiber content from 0.0% to 1.0% reduces the permeability of FRC and FRFAC by 36.7% and 45.5% respectively. The permeability of cracked FRC increases by 11.4 to 52.0% over the corresponding uncracked specimen for percentage of fibers varying from 0.0 to 1.0%. Whereas, the permeability of cracked FRFAC increases by 6.5 to 52.4% over the corresponding uncracked specimen for percentage of fibers varying from 0.0 to 1.0%. The reason for this increasing trend of permeability with the increase of fiber content is due to more internal damage occurring in concrete when fiber content is more because the damage gets distributed thus giving continuity to cracks. The increase in the permeability of cracked specimen of FRC and FRFAC over the corresponding uncracked concrete is almost the same. The variation of permeability of cracked as well as uncracked FRC and FRFAC with the fiber content is almost linear. The equation of the models is written in the figure and reported in Table 4.

3. Results and Discussion

The conclusions derived from the present study are:

The compressive strength, crushing strain and Poisson's ratio of FRC and FRFAC increase almost linearly with increase in the percentage of fibers upto 1%. The stress-strain curves of FRC and FRFAC are parabolic with almost linear portion upto 30% of the uniaxial

compressive strength. The initial tangent modulus of FRC and FRFAC is 32 GPa for both FRC and FRFAC, which is independent of the quantity of fibers. The increase in the quantity of fibers from 0.0 to 1.0% results in approximately 39.6% and 41.8% increase in the compressive strength of FRC and FRFAC respectively. The compressive strength of FRFAC is 6 to 9% more than that of FRC, which is because of the formation of additional calcium silicate hydrates in the hydrated cement matrix because of the addition of fly ash. The increase in crushing strain of FRC and FRFAC with the increase in the quantity of fibers from 0.0 to 1.0% is 58.3 and 82.7% respectively, which indicates that the addition of fibers introduces ductility in concrete. Though there is nominal increase in the value of Poisson's ratio with the increase in the fiber content, however, the value of Poisson's ratio for practical purposes may be taken as 0.2, independent of fiber content, for FRC as well as FRFAC. Most of the cracks are almost along the line of action of the load, which indicates that the failure is mainly by lateral tension and shear failure of specimen close to the platens is observed in some of the specimen. The cracks are not straight and have branches, which is due to the presence of fibers. The first visual crack observed by naked eye is at 30% of the uniaxial compressive strength of FRC and FRFAC.

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