

EFFECT OF STEEL AND POLYPROPYLENE FIBRES ON STRENGTH CHARACTERISTICS OF FLY ASH REINFORCED CONCRETE

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in partial fulfilment of the requirements for
the award of the degree of

**MASTERS OF ENGINEERING
IN
STRUCTURAL ENGINEERING**

Submitted by:
**RAMANDEEP SINGH DHILLON
(ROLL NO. 801122017)**

UNDER THE GUIDANCE OF:

DR. SHRUTI SHARMA

Assistant Professor

Dept. of Civil Engg.

DR. GURBIR KAUR

Assistant Professor

Dept. of Civil Engg.



**DEPARTMENT OF CIVIL ENGINEERING
THAPAR UNIVERSITY, PATIALA 147004**

JULY 2013

DECLARATION

I hereby declare that the work which is presented in this thesis report entitled “Effect Of Steel And Polypropylene Fibres On Strength Characteristics Of Fly Ash Reinforced Concrete”, in partial fulfillment of the requirement for the award of degree of MASTER OF ENGINEERING (STRUCTURAL ENGINEERING) in the CIVIL ENGINEERING DEPARTMENT, THAPAR UNIVERSITY, PATIALA, is an authentic record of the initial work carried out under the supervision of Dr. Shruti Sharma, Assistant Professor, DEPARTMENT OF CIVIL ENGINEERING, THAPAR UNIVERSITY, PATIALA. The matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.



(RAMANDEEP SINGH DHILLON)

Roll No. 801122017

CERTIFICATE

This is to certify that the above declaration made by the student concerned is correct to the best of my knowledge and belief.



DR. SHRUTI SHARMA
Assistant Professor
Civil Engineering
Thapar University, Patiala



DR. GURBIR KAUR
Assistant Professor
Civil Engineering
Thapar University, Patiala

Countersigned



DR. NAVEEN KWATRA
Head and Associate Professor,
Civil Engineering,
Thapar University, Patiala



DR. S.K. MOHAPATRA
Dean Academic Affairs,
Thapar University, Patiala

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RAMANDEEP SINGH DHILLON

M.E CIVIL STRUCTURES

ROLL NO 801122017

ABSTRACT

With the ever-increasing population of the world, in general, and the developing countries, in particular, there is tremendous pressure on Civil Engineers to develop cost-effective and eco-friendly structures to fulfill the needs of the mankind. Within current practices of utilization, cement and concrete construction industries throughout the world has been the largest user of flyash, an industrial by-product, whose use and production have increased many fold during last three decades and have exploited it to the best advantage. Flyash nowadays is a fourfold issue: reduction in air/water pollution, beneficial conversion of waste into wealth, reduction in expenditure on disposal and augmenting the demand of much needed construction materials which is economical and sound. Fibres on other hand have provided to improve strength, stiffness and ductility of reinforced concrete members with their addition. They act as crack arrestors, change all modes of failure, and increase ultimate strain of the composite.

Experimental investigation has been carried out to study the effect of the fly ash content with steel and polypropylene fibres on the properties of concrete. Cement has been replaced by mass with 15,20 and 25 per cent fly ash content. Two percentages of steel fibres (0.5 and 1.0 per cent) of aspect ratio 50 and same percentage of polypropylene fibres (0.5 and 1.0 percent), have been used in the investigation. Tests have been performed for Compressive strength, split tensile strength and flexural strength of different specimens.

Test results indicate with the increase in percentage of fly ash content, the compressive strength, split tensile strength and flexural strength of concrete decreases but this decrease is compensated by the use of fibres in concrete. Steel fibres give better results than polypropylene fibres. Also with the percentage increase in fibre content, the strength increases.

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1.1 General

Concrete is currently the most widely used construction material as it can be cast to any form and shape at site very easily. However, the relative low tensile strength to weight ratio and limited ductility of plain cement concrete poses major difficulty in its direct applications. Reinforcement is used to absorb these tensile forces. Microcracks are present in concrete and because of its poor tensile strength; the cracks propagate with the application of load, leading to brittle fracture of concrete.

The focus of the current research is to enhance the concept of use of fibres in concrete (Steel as well as polypropylene) to increase the concrete ductility and its strength, as well as to improve overall durability. The fibres are randomly dispersed throughout the concrete matrix providing for better distribution of both internal and external stresses by using a three dimensional reinforcing network. Effect of both steel and polypropylene fibres is investigated in this study.

The primary role of the fibres in hardened concrete is to modify the cracking mechanism. By modifying the cracking mechanism, the macro cracking becomes microcracking. The cracks are smaller in width, thus reducing the permeability of concrete and the ultimate cracking strain of the concrete is enhanced. The fibres are capable of carrying a load across the crack. The weak matrix in concrete, when reinforced with steel fibres, uniformly distributed across its entire mass, gets strengthened enormously, thereby rendering the matrix to behave as a composite material with properties significantly different from conventional concrete. Because of the vast improvements achieved by the addition of fibres to concrete, there are several applications where Fibres Reinforced Concrete (FRC) can be intelligently and beneficially used. The principal fibres in common commercial use for Civil Engineering applications include steel (SFRC/SFRS), glass, carbon and aramid. These fibres are also used in the production of continuous fibres and are used as a replacement to reinforcing steel.

The fibre reinforcement may be used in the form of three – dimensionally randomly distributed fibres throughout the structural member when the added advantages of the fibre to shear resistance and crack control can be further utilised. On the other hand, the fibre

concrete may also be used as a tensile skin to cover the steel reinforcement when a more efficient two – dimensional orientation of the fibres could be obtained.

Fly ash which is a by-product of the thermal power plant poses serious problems of its dumping to the environmentalists. Utilization of fly ash in concrete as partial replacement with cement not only solves the problems of dumping to some extent but also it is used as mineral admixture in concrete and helps to attain reduction in cost of concrete by saving cement. This pozzolana is beneficially used to attain certain properties in concrete as lower water demand for similar workability, reduced bleeding and lower evolution of heat. It has been used particularly in mass concrete applications and large volume placement to control expansion due to heat of hydration and also helps in reducing cracking at early ages.

Plain concrete is weak in tension and has limited ductility and little resistance to cracking. Micro-cracks are present in concrete and because of its poor tensile strength; the cracks propagate with the application of load, leading to brittle fracture of concrete.

Micro-cracks in concrete are formed during its hardening stage. A discontinuous heterogeneous system exists even before the application of any external load. When the load is applied, micro-cracks start developing along the planes, which may experience relatively low tensile strains, at about 25-35% of the ultimate strength in compression. Further application of the load leads to uncontrolled growth of the micro-cracks. The low resistance to tensile crack propagation in turn results in a low fracture toughness, and limited resistance to impact and explosive loading. The low tensile strength of concrete is being compensated for in several ways, and this has been achieved by the use of reinforcing bars and also by applying prestressing method.

Though these methods provide tensile strength to concrete, they do not increase the inherent tensile strength of concrete itself. Further, conventionally reinforced concrete is not a two phase material in true sense. Conventionally reinforced concrete a true two phase material only after cracking when cracked matrix is held by the reinforcing bars. Existence of one phase (i.e. steel or concrete) does not improve the basic strength characteristics of the other phase and consequently the overall performance of the traditional reinforced concrete composite is dictated by the individual performance of the concrete and steel phase separately. These deficiencies have led researchers to investigate and develop a material could perform better in areas where conventional concrete has several limitations. Current research has developed a new concept to increase the concrete ductility and its energy absorption capacity, as well as to improve overall durability. This new generation

technology utilizes discrete steel or synthetic fibres from 19 to 64 mm in length. The fibres are randomly dispersed throughout the concrete matrix providing for better distribution of both internal and external stresses by using a three dimensional reinforcing network.

The primary role of the fibres in hardened concrete is to modify the cracking mechanism. By modifying the cracking mechanism, the macro cracking becomes micro-cracking. The cracks are smaller in width, thus reducing the permeability of concrete and the ultimate cracking strain of the concrete is enhanced. The fibres are capable of carrying a load across the crack.

1.2 Aim

The main aim of this research is to investigate and evaluate the effectiveness of using Steel fibres vis-à-vis Polypropylene fibres in Concrete. Partial replacement of Cement is made by using fly ash.

1.3 Objectives

The main objective of the thesis can be summarized as:

- Investigate the characteristics of concrete made by partial replacement of cement with fly ash to make it modified concrete.
- Investigate the strength characteristics (compressive, split tensile and flexural strength) of concrete modified with fly ash and further addition of variable proportions of steel fibres (0.5% and 1%).
- Study the strength characteristics (compressive, split tensile and flexural strength) of concrete modified with fly ash and further addition of variable proportions of polypropylene fibres (0.5% and 1%).
- Compare the effects of various types of fibres for efficient performance interests of strength and workability.

1.4 Steel Fibre Reinforced Concrete (SFRC)

The randomly-oriented steel fibres assist in controlling the propagation of micro-cracks present in the matrix, first by improving the overall cracking resistance of matrix

itself, and later by bridging across even smaller cracks formed after the application of load on the member, thereby preventing their widening into major cracks. The idea that concrete can be strengthened by fibre inclusion was first put forward by Porter in 1910, but little progress was made in its development till 1963, when Roumaldi and Batson carried out extensive laboratory investigations. Since then, there has been a great wave of interest in and applications of SFRC in many parts of the world. While steel fibres improve the compressive strength of concrete only marginally by about 10 to 30%, significant improvement is achieved in several other properties of concrete.

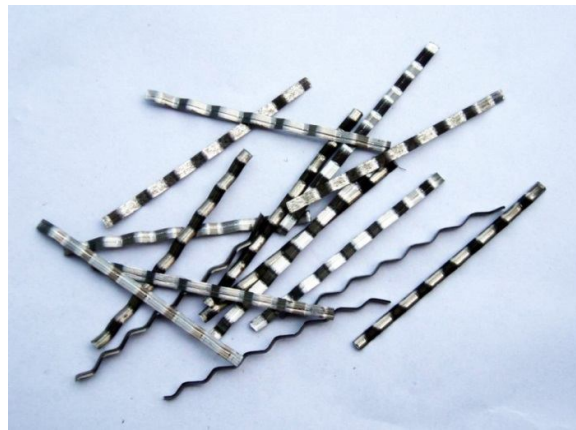


Fig1.1: Steel fibres used in study (Crimped style)

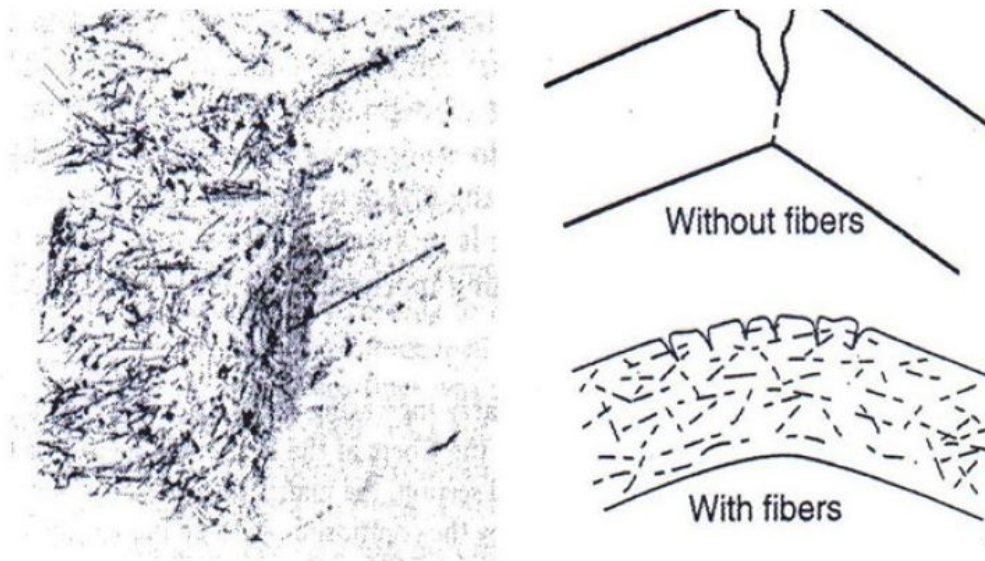


Fig. 1.2: Failure mechanism and the effect of fibres

In general, SFRC is very ductile and particularly well suited for structures which are required to exhibit:

- Resistance to impact, blast and shock loads and high fatigue.
- Shrinkage control of concrete (fissuration).
- Very high flexural, shear and tensile strength.
- Resistance to splitting/spalling, erosion and abrasion.
- High thermal/ temperature resistance.
- Resistance to seismic hazards.

1.4.1 General Application of Steel Fibres

Steel Fibre Reinforced Concrete or Shotcrete (SFRC/SFRS) have been used in various applications throughout the world. In India their use is picking up slowly. The principal advantages of SFRC versus plain or mesh/bar reinforced concretes are:

- Cost savings of 10% - 30% over conventional concrete flooring systems.
- Reinforcement throughout the section in all directions versus one plane of reinforcement (sometimes in the sub-grade) in only two directions.
- Increased ultimate flexural strength of the concrete composite and thus thinner sections.
- Increased flexural fatigue endurance and again thinner slabs.
- Increased flexural toughness, or the ability to absorb energy.
- Increased impact resistance and thus reduced chipping and joint spalling.
- Increased shear strength and thus the ability to transfer loads across joints in thin sections.
- Increased tensile strength and tensile strain capacity thus allowing increased contraction/construction joint spacing.



Fig 1.3 Application of Fibre reinforced concrete (FRC) in modern industries

1.4.2 Advantages and Limitations of Fibre reinforced concrete (FRC)

Fibres, which are randomly distributed throughout the concrete, can overcome cracks and control shrinkage more effectively. These materials have outstanding combinations of strength and energy absorption capacity. In general, the fibre reinforcement is not a substitution for conventional steel reinforcement. The fibres and steel reinforcement has their own role in concrete technology. However, fibres are not efficient in withstanding the tensile stresses compare to conventional steel reinforcement. But, fibres are more closely spaced than steel reinforcement, which are better in controlling crack and shrinkage. Consequently, conventional steel reinforcement used to increase the load bearing capacity of concrete member; fibres are more effective in crack control. Due to these differences, there are particular applications that fibres reinforced are advance than conventional steel reinforcement. These include:

- Fibres comprise as 'primary reinforcement', in which the conventional steel reinforcement cannot be utilized. The fibre concentrations are comparatively high in thin sheet materials, normally exceeding 5% by volume, acts to increase in toughness and strength of mortar or concrete.
- Fibres can be components to withstand locally high loads or deformations, which

applies to structures like Precast piles, Precast walls, blast resistant structures or sewer tunnel and linings.

- Applications that control cracks persuaded by temperature and humidity, such as pavements and slabs, where fibres offered as 'secondary reinforcement'.

The uses of steel bars and wire mesh require unnecessary labour and material costs for structure concrete. With replacement of randomly distributed short fibres as an alternative reinforcement, will significantly reduce both labour and material costs, greatly increase construction and project time. Fibres substantially reduce formation of plastic shrinkage and settlement; enable the concrete to develop its potential long-term application to structural concrete, providing solution to exceed and meet their performance and economical prospect. Additionally, fibres provide an effective secondary reinforcement for shrinkage and crack width control. Macro -cracks and potential problems are prevented and blocked when micro -cracks intersect fibres as concrete hardens and shrink.

1.5 Polypropylene Fibre

Polypropylene is a synthetic hydrocarbon polymer, the fibre of which is made using extrusion processes by hot drawing the material through a die. Its use enables reliable and effective utilization of intrinsic tensile and flexural strength of the material along with significant reduction of plastic shrinkage cracking and minimizing of thermal cracking. It has been established that the addition of randomly distributed polypropylene fibres to brittle cement based materials can increase their fracture toughness, ductility and impact resistance. Since fibres can be premixed in a conventional manner, the concept of polypropylene fibre concrete has added an extra dimension to concrete construction.

Tavakoli (1994), performed experiments on concrete specimens reinforced randomly with propylene fibres. The results showed that compressive strength did not change significantly, but tensile strength had an increase of about 80%.

Patel et al.(2012), Strength enhancement in splitting tensile strength due to polypropylene fibre addition varies from 5% to 23%. Split tensile strength at 28 days is approximately 50% higher than 7 day's strength.

Recron 3s Fibre

Recron Fibre fill is India's only hollow Fibre specially designed for filling and insulation purpose. Made with technology from DuPont, USA, Recron Fibrefill adheres to world-class

quality standards to provide maximum comfort, durability, and ease-of-use in a wide variety of applications like sleep products, garments and furniture. Reliance Industry Limited (RIL) has launched Recron 3s fibres with the objective of improving the quality of plaster and concrete. Fig 1.4 shows the Recron 3s fibres. Table 1.1 gives standard specifications used for Recron 3s fibres.



Fig 1.4: Recron 3s fibre

Table 1.1: Specification of Recron

Characteristics	Specifications
Denier	1.5d
Cut Length	6mm,12mm,24mm
Tensile Strength	About 6000 kg/cm ²
Melting Point	250° C
Dispersion	Excellent
Acid Resistance	Excellent
Alkali Resistance	Good

Advantages of Recron 3s

- It results in thinner and stronger elements when used in low dosage arrests cracking.

- It prevents the shrinkage cracks developed during curing making the structure/plaster/component inherently stronger.
- Further when the loads imposed on concrete approach that for failure, cracks will propagate, sometimes rapidly. Addition of RECRON 3s in concrete and plaster prevents/arrests cracking caused by volume change (expansion & contraction).
- A cement structure free from such micro cracks prevents water or moisture from entering and migrating throughout the concrete which helps prevent the corrosion of steel used for primary reinforcement in the structure. This in turn improves longevity of the structure.
- The modulus of elasticity of RECRON 3s is high with respect to the modulus of elasticity of the concrete or mortar binder.
- The RECRON 3s fibres help increase flexural strength. RECRON 3s fibres are environmental friendly and non-hazardous. They easily disperse and separate in the mix.
- Only 0.2-0.4% by cement RECRON 3s is sufficient for getting the above advantages. Thus it not only pays for itself, but results in net gain with reduced labour cost & improved properties.

So we can briefly summarize the advantages of Recron 3s fibre as:

- Control cracking
- Increase flexibility
- Reduction in water permeability
- Reduction in rebound loss in concrete
- Safe and easy to use

This can be used in various aspects such as:

- PCC and RCC plastering
- Shortcrete and gunniting
- Slabs, footings, foundations, walls and tanks
- Pipes, prestressed beam etc
- Concrete blokes, railway sleepers, manhole cover and tiles etc
- Roads and pavements
- Bridges and dams

1.6 Fly Ash

Fly ash is the residue obtained from combustion of pulverized coal collected by the mechanical or electrostatic separators from the fuel gases of thermal power plants. Its composition varies with the type of fuel burnt, load on boiler and type of separator etc. Fly ash consists mainly of spherical glassy particles ranging from 1 to 150 micro-meters in diameter, out of which the bulk passes through a 45 micro-meter sieve. The fly ash obtained from electrostatic precipitators is finer than Portland cement. The fly ash obtained from cyclone separators is comparatively coarse. The carbon content in fly ash should be as low as possible, whereas the silicon content should be as high as possible. The fly ash may be used in concrete either as an admixture or in part replacement of cement. The pozzolanic activity is due to the presence of finely divided glassy silica and lime, which produce calcium silicate hydrate (CS H) responsible for strength development. Due to the difference in densities of cement and fly ash, a part replacement by equal mass increases the volume of cementitious material; whereas replacement by equal volume reduces the mass in practice the replacement of cement by fly ash is usually on the mass basis. As per ASTM –C 618-93 fly ash and natural pozzolans are classified into the following into three categories:

- CLASS N: Raw or calcined natural pozzolons such as some diatomaceous earths, opaline chert and shale, stuffs, volcanic ashes and pumice are come in this category.
- CLASS F: Fly ash normally produced from burning anthracite or bituminous coal falls in this category. This class of fly ash exhibits pozzolanic property but rarely if any, self-hardening property due to low lime content (<10%).
- CLASS C: Fly ash usually produced from lignite or subbituminous coal is the only material included in this category. It has both pozzolanic and varying degree of self cementitious properties due to high lime content (> 10%)

Table 1.2 gives the chemical requirements of fly ash for using in concrete. Table 1.3 gives the detailed physical requirements of fly ash for using in concrete.

Table 1.2 Chemical requirements of Fly ash (IS: 3812-1981)

Sr. No	Characteristic	Requirement
1.	Silicon dioxide (SiO ₂) plus aluminium oxide (Al ₂ O ₃) plus iron oxide (Fe ₂ O ₃), per cent by mass, Min.	70
2.	Silicon dioxide (SiO ₂), per cent by mass, Min 35.0	35
3.	Magnesium oxide (MGO), per cent by mass, max 5.0	5.0
4.	Total sulphur trioxide (SO ₃), per cent by mass, max 2.75	2.75
5.	Available alkalis as sodium oxide Na ₂ O, per cent by mass, max 1.5	1.5
6.	Loss in ignition, per cent by mass, max 12.0	12.0

Table 1.3 Physical requirements of Fly ash (IS: 3812-1981)

Sr. No.	Characteristics	Requirement	
		Grade of Fly ash	
		I	II
1.	Fineness, specific surface in m ² /kg by Blaine's permeability method, Min	320	4.0
2.	Lime reactivity Average compressive stress in N/mm ² , Min	4.0	3.0
3.	Compressive strength at 28 days in N/mm ² , Min	Not less than 80% of the strength of corresponding plain cement mortar cubes	
4.	Drying shrinkage, per cent, max 0.15 0.10	0.15	0.10
5.	Soundness by autoclave test expansion of specimens, per cent, Max	0.8	0.8

1.7 Closing Remarks

This chapter establishes the need for use of fly ash in concrete. As fly ash reduces the strength of concrete but improves its workability so in order to compensate the strength parameters nominal proportions of steel as well as poly propylene fibres are used.

In this chapter research work related to the use of fibres, flyash as well as fibre in concrete as reported by various authors has been presented in respective sequence.

2.1 Review of latest work done by different authors:

Shah and Ranjan(1971) have investigated mechanical properties of concrete and mortar reinforced with randomly distributed smooth steel fibres. Different volumes, lengths, orientations and types of fibres were used. Fibres were compared with conventional reinforcement in flexural tension and compression. It was observed that the significant reinforcing effect of fibres is derived after the cracks are initiated in the matrix. The post cracking resistance of fibres is considerably influenced by their lengths orientation on stress-strain relationship. The spacing of reinforcement appears to have little influence on crack propagation below a certain length. The reinforcing action of fibres was analytically predicted by using the composite materials approach based on the properties of individual components.

Gunasekran(1975) has conducted tests to investigate the flexural strength and load deflection behaviour of light weight concrete beams (150mm x 150mm x 900mm) made with sintered flyash aggregates and regulated set cement and included steel fibre reinforcement. Three different aspect ratios of about 47, 50 and 63 were used for the fibres. It was found that beams containing fibres with an aspect ratio of 50 had the best flexural strength 34.5 Kg/m but the beams containing fibres with an aspect ratio of 62.5 had better ductility, although lower flexural strength, 25.3 kg/cm². They have concluded that for equal quantities of fibre reinforcement, a blend of fibres consisting of both long and short fibres results in greater structural benefits in concrete than identical fibres with a high aspect ratio, and low aspect ratio fibres act as crack arresters in the finite volume enclosed by the high aspect ratio fibres, the latter are primarily responsible for the enhanced ductility of fibre reinforced concrete.

Ramakrishnan et al.(1980) have presented a comparative evaluation of two types of steel fibres used as reinforcing materials in concrete. The fibres used were 25.4 mm long straight fibres and 51 mm long fibres with deformed ends which were glued together into bundles with water soluble adhesive. They conducted tests for (1) Flexural fatigue (2) Static flexural

strength including strain, deflection, modulus of rupture, load deflection curves, determination of first crack load and determination of post cracking strength of two sizes of beams (3) Impact strength (4) Compressive Strength and (5) Plastic workability. The complete series of tests was run for two concentrations of the collected and hooked fibres and with pozzolana and straight cement mixes.

Based on the experimental investigation they concluded that balling of fibres occurred in the case of hooked fibres even though they were dumped into the mixes all at once along with the aggregate. The compressive strength of the fibrous concrete is slightly higher than the compressive strength of plain concrete mix. The static flexural test showed that an excellent and enchorage is established between the hooked fibre and the matrix, resulting in a high ultimate flexural strength, high load carrying capacity and high ductility of the composite material. The hooked fibre reinforced concrete shows a greater ability to absorb impact loading than straight fibre reinforced concrete.

For the two hooked fibre concentrations, no significant difference was recorded in the ultimate flexural strength, post cracking load carrying capacity and ductility. However impact resistance and toughness increased with fibre content.

Swamy and Al-Tann(1981) have presented an extensive experimental data on the deformation characteristics and ultimate strength in flexure of concrete beams made with 20 mm maximum size of aggregates and reinforced with bar reinforcement. Fibres were provided either over the whole depth of beams or in the effective tension zone only surrounding the steel bars. It was shown that the ultimate strength is increased marginally, the fibres arrest cracks and increases post cracking stiffness at all stages of loading upto failure which results in narrow crack widths and less deformation. The tests showed that at failure, the compressive strains reached values of 0.005 to 0.006 and reinforcing bars attain stresses well in excess of their yield strengths. They further proposed on ultimate strength theory, which shows good agreement with the experimental data.

Malhotra and Berry(1986) studied polypropylene fibre reinforced high volume fly ash concrete having a low water to cementitious material ratio , fly ash content greater than 50 percent of the cementitious material, and contents of fibres up to 5 kg/m³ of concrete. The workability of the concrete is maintained by the use of high dosages of superplasticizers. By their studies it was concluded that polypropylene fibre reinforced high volume fly ash concrete has satisfactory workability and strength characteristics. It was also concluded that polypropylene fibre reinforced high volume fly ash concrete has very low permeability, low

drying shrinkage, adequate ductility and toughness characteristics.

Bayasi and Soroushian(1987) have studied the effects of partial substitution of cement with flyash in steel fibre reinforced concrete on the fresh and the hardened material properties. The 28-day flexural cracking and ultimate loads and the corresponding flexural deformations, as well as the flexural energy absorption capacity and toughness tend to increase with increasing flyash content of the mix upto a flyash cementitious ratio of 0.3. The increase of flyash cementitious ratio from 0.3 to 0.4, however, adversely influences all aspects of the flexural performance of the fibrous materials.

Kukreja and Chawla(1989) published their paper on “Flexural characteristics of steel fibre reinforced concrete.” They used three shapes of fibres viz. straight, bent and crimped with varying volume percentages viz. 0.5, 1.0 and 1.5 aspect ratio being the same as 80 in all the cases. Based on their study they concluded that the flexural strength alone does not adequately describe the behaviour of fibrous concrete. Depending upon steel fibre content its type and orientation, behaviour can range from brittle to very ductile, all for the same range of flexural strength. Flexural stiffness of the fibrous concrete is higher than that of ordinary concrete, emphasizing the ability of the fibres to arrest cracks due to the bridging action of fibres.

Ali et al.(1995) have reported the structural behaviour of steel fibre reinforced flyash concrete under compression and flexure by conduction test on standard control specimens. Fibre reinforced concrete is very much effective in resisting the flexural tensile stresses as compared to compressive stresses as long as flyash replacement is less than 30% Specimens containing 0.5% and 1.0% fibres with 20% and 30% replacement of cement by flyash are most effective in doing the same.

Chenkui and Guofan(1995) study the properties, such as tensile, compressive, flexural strength, flexural toughness and flexural fatigue strength, of steel fibre reinforced concrete containing larger aggregate with maximum size of 40 mm. The experimental program consisted of two parts. The first part was a static experimental program to study the effect of steel fibre, the size of aggregate on concrete properties and to choose the mixture proportion. The second part was a fatigue experimental program .They conclude that steel fibres are not only used to reinforce fine stone concrete but also used to reinforce the concrete containing larger aggregate with maximum size of 40 mm, provided that the steel fibres are not shorter than 35 mm also they conclude that fibre concrete containing larger crushed stone demonstrated a good fatigue performance in both laboratory test and field

trial. Fig 2.1 shows the results of the authors giving relationship between Splitting tensile (MPa) and Length of fibre(mm).

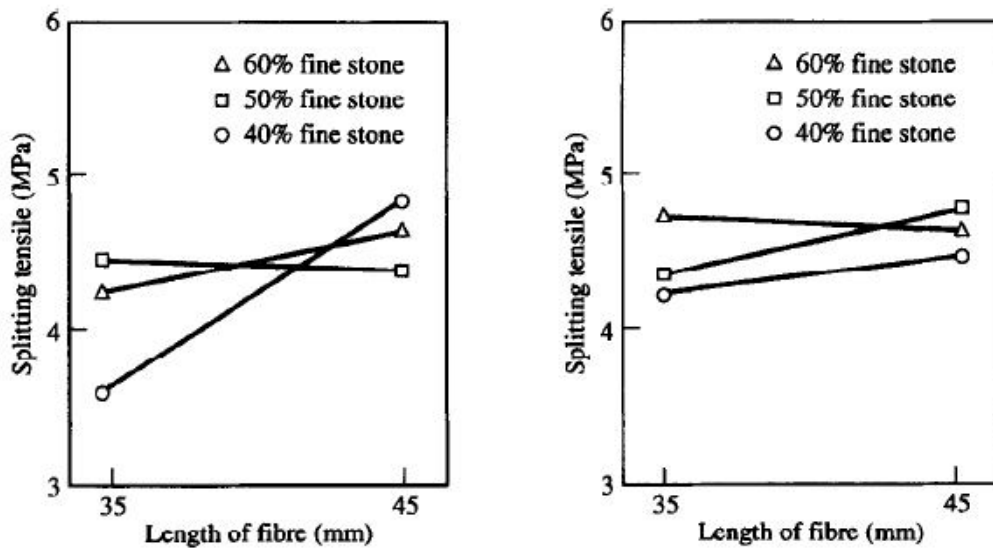


Fig 2.1: Relationship between tensile strengths and length of steel fibre.

Alhozaimyet al.(1996) studied the effects of collated fibrillated polypropylene fibres at relatively low volume fractions (below 0.3%) on the compressive, flexural and impact properties of concrete material with different binder compositions. Two experimental programs were designed for studying the compressive and flexural properties and impact resistance of polypropylene fibre reinforced concrete. In phase I, the effect of polypropylene fibre volume fraction was investigated in a one-way experimental design with five different volume fractions (0.0, 0.05, 0.1, 0.2, and 0.3%). In the second experimental design, the effects of pozzolanic materials in polypropylene fibre reinforced concrete were assessed. The matrix composition in some mixtures was adjusted through partial substitution of Portland cement with a pozzolanic material (fly ash, slag, or silica fume). Table 2.1 presents the chemical compositions of the cement and pozzolanic materials used.

Table 2.1: Chemical composition of Binder

<i>Binder type</i>	<i>CaO</i>	<i>SiO₂</i>	<i>Al₂O₃</i>	<i>Fe₂O₃</i>	<i>SO₃</i>	<i>MgO</i>	<i>K₂O</i>	<i>C</i>	<i>Na₂O</i>
Cement	63.24	21.14	5.76	2.93	2.46	2.06	0.79	—	—
Fly Ash	2.6	47.00	22.10	23.40	—	0.76	2.00	4.30	—
Silica Fume	—	96.50	0.15	0.15	—	0.20	0.04	1.40	0.20
Slag	—	35.40	11.40	0.60	1.02	13.00	0.34	—	0.10

Polypropylene fibres have no statistically significant effects on the compressive strength and flexural strength. Whereas, Flexural toughness is significantly effected at 95% level of confidence. While pozzolans generally reduce the impact resistance of concrete.

Zhang et al.(1999) investigated the materials used, mixture proportions, mixing and shotcreting operation and properties of the fresh and hardened polypropylene fibre reinforced shotcrete incorporating silica fume and high volumes of fly ash. The polypropylene fibre reinforced high volume fly ash shotcrete produced had satisfactory workability, mechanical properties and resistance to freezing and thawing cycling. The shotcrete containing silica fume had negligible rebound compared with that without silic a fume. The incorporation of fly ash and silica fume improved the workability of the fresh shotcrete and this resulted in lower operation pressure for the shotcreting. The use of polypropylene fibres upto .5% by the volume of the shotcrete did not affect s ignificantly the compressive strength and the shotcrete incorporating both fly ash and silica fume bonded well to the base concrete. The fibre –reinforced shotcrete showed satisfactory performance after 300 cycles of freezing and thawing with a durability factor >80 even though the air contents were relatively low and spacing factor was relatively high.

Qian and Stroeven(2000) had investigated the optimization of fibre size, fibre content, and fly ash content in hybrid polypropylene-steel fibre concrete with low fibre content. Additions of a small fibre type had a significant influence on the compressive strength, but the splitting tensile strength was only slightly affected. A large fibre type gave rise to opposite mechanical effects, which were further fortified by optimization of the aspect ratio. There is a synergy effect in the hybrid fibres system. It can be seen that 50 to 100 kg/m³ of fly ash is necessary for hybrid concrete to obtain better static properties, which is also a reference of microstructure of the concrete. The higher the strength, the denser the structure is as the fibre content is the same.

Table 2.2 shows mix proportions with varying percentage of fibre content and fly ash

Hybrid fibre concrete with different content of fly ash

Mix no.	Fly ash (kg/m ³)	Superplasticizers (%)	Fibre content (% by volume of concrete)				
			PP	SF1	SF2	SF3	Total
F11	100	2.5	0.3	0	0.2	0.4	0.9
F51	50	2.5	0.3	0	0.2	0.4	0.9
F01	0	2.5	0.3	0	0.2	0.4	0.9
F12	100	2.5	0.15	0.2	0.2	0.2	0.75
F52	50	2.5	0.15	0.2	0.2	0.2	0.75

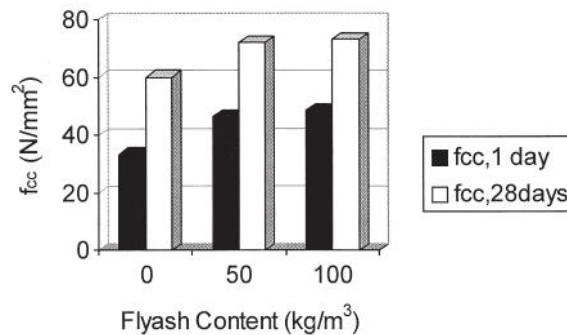


Fig 2.2 shows the relation between fly ash and compressive strength of concrete

Siddique(2003) reported the results of an experimental investigation to study the effects of replacement of cement (by mass) with three percentages of fly ash and the effect of addition of natural san fibres on the slump, Vee-bee time, compressive strength, splitting tensile strength, flexural strength and impact strength of fly ash concrete. San fibres belong to the category of natural blast fibres. This class of natural fibre is mostly grown in the Indian subcontinent, Brazil, Eastern and Southern Africa and some parts of the United States. A control mixture of proportions 1:1.4:2.19 with w/c ratio of 0.47 and superplasticizer/cementitious ratio of 0.15 was designed. Cement was replaced with three percentages (35%, 45%, and 55%) of class F fly ash. Three percentages of san fibres (0.25%, 0.5% and 0.75%) having 25mm length were used. The test results indicated that replacement of cement with fly ash increased the workability, decreased compressive strength, splitting tensile strength and flexural strength and had no significant effect on the

impact strength of plain concrete. Addition of san fibres reduced the workability, did not significantly affect the compressive strength, increased the splitting tensile strength and flexural strength and enhanced the impact strength of fly ash concrete as the percentage of fibres increased.

Siddique(2004) reported the results of an experimental investigation dealing with concrete incorporating high volumes of class F fly ash. Portland cement was replaced with three percentages (40%, 45% and 50%) of class F fly ash. Tests were performed for fresh concrete properties (Slump, unit weight and temperature). Compressive, splitting and flexural strengths, modulus of elasticity were determined up to 365 days of testing. Test results indicated that the use of high volumes of class F fly ash as a partial replacement of cement in concrete decreased its 28 day compressive, splitting tensile and flexural strengths, modulus of elasticity. However all these strength properties showed significant improvement at the ages of 91 and 365 days, which was most probably due to the Pozzolanic reaction of fly ash. Based on results it was concluded that Class F fly ash could be suitably used up to 50 % level of cement replacement in concrete for use in precast elements and reinforced cement concrete construction.

Bekir and Canbaz(2007) gave experimental investigation to study the effects of replacement of cement (by weight) with three percentages of fly ash and effects of addition of steel and polypropylene fibres. Table 2.3 gives the details of fibres used by the authors in the study. According to the results of the study, addition of fibres provide better performance for the concrete, while fly ash in the mixture may adjust the workability and strength losses caused by fibres, and improve strength gain.

Table 2.3: Physical and mechanical properties of fibres

Fibre type	Thickness of fibre (µm)	Length (cm)	Relative density	Tensile strength (MPa)	Elastic modulus (GPa)	Ultimate elongation (%)	Ignition temperature (°C)	Melt temperature (°C)
PPI	50	2.3	0.91	350	4.2	15	600	165
PPII	36	1.2	0.90	325	4	20	600	165
SF	55	3.5	7.8	400	200	18	-	-

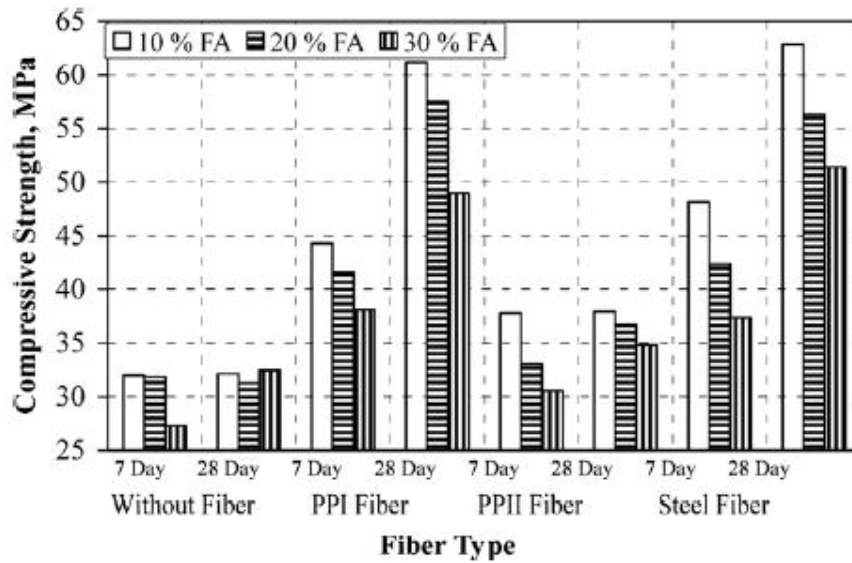


Fig 2.3 shows the relation between compressive strength and fibre type.

Fig 2.3 shows the relationship between compressive strength and fibre type. From the results it is clear that fibres hindered the flow ability of fresh concrete and this caused the decrease in workability of concrete. It is seen that compressive strength of concrete produced with fibres were increased compared to concrete produced without fibres. Tensile strength of PPII fibre is lower than PPI and steel fibres. It can be seen that bending strength of concrete produced with fibres increased compared to concrete produced without fibres.

Cengiz and Okan(2009) had presented paper reports on a comprehensive study on the properties of concrete containing fly ash and steel fibres. Fly ash content used was 0%, 15% and 30% in mass basis, and fibre volume fraction was 0%, 0.25%, 0.5%, 1.0% and 1.5% in volume basis. It is observed that steel fibres did not recover the compressive strength loss of fly ash. Steel fibres have no significant effects on flexural tensile strength at 0.25% and 0.5% volume fractions used in this study. Increasing the amount of steel fibre reduces drying shrinkage. While fly ash reduce the drying shrinkage of concrete, the positive interactions between steel fibres and fly ash leads to lower drying shrinkage of fibrous concrete with fly ash.

Behnood and Ghandehari(2009) investigated the compressive and splitting tensile strength of high-strength concrete with and without polypropylene(PP) fibres after heating to 600 degree C. Mixtures were prepared with water to cementitious materials ratios of

0.40, 0.35, and 0.30 containing silica fume at 0%, 6%, and 10% cement replacement and polypropylene fibres content of 0, 1, 2, and 3 kg/m³. Fig 2.4 shows the relationship between splitting tensile strength and fibre volume fraction. A severe strength loss was observed for all of the concretes after exposure to 600 degree C, particularly the concretes containing silica fume despite their good mechanical properties at room temperature. The range of 300–600 degree C was more critical for concrete having higher strength. The relative compressive strengths of concretes containing PP fibres were higher than those of concretes without PP fibres. The splitting tensile strength of concrete was more sensitive to high temperatures than the compressive strength.

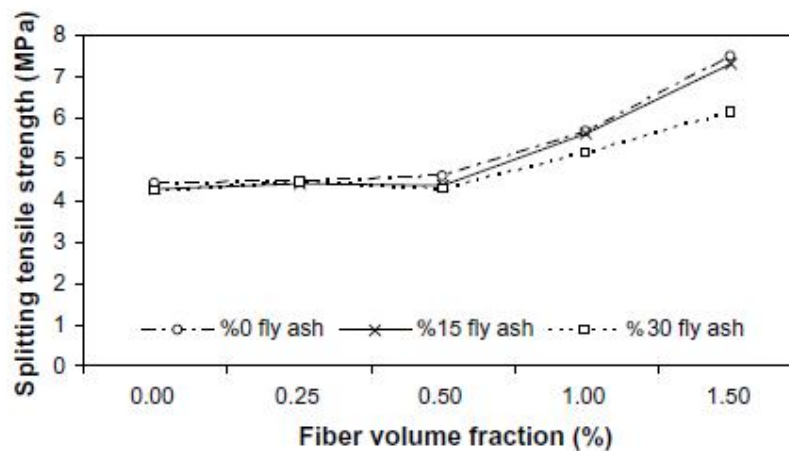


Fig 2.4: shows the relation between splitting tensile strength and fibre volume fraction

Duran and Karahan(2010)They reports comprehensive study on the durability properties of concrete containing polypropylene fibre and fly ash. Fly ash content used in concrete mixture was 0%, 15% and 30% in mass basis, and fibre volume fraction was 0%, 0.05%, 0.10% and 0.20% in volume basis. The laboratory result shows that inclusion of fly ash improves the workability; polypropylene fibre decreases the same. Moreover, polypropylene fibre addition, either into Portland cement concrete or fly ash concrete, did not improve the compressive strength and elastic modulus. The positive interactions between polypropylene fibres and fly ash lead to the lowest drying shrinkage of fibrous concrete with fly ash. Freeze–thaw resistance of polypropylene fibre concrete was found to slightly increase when compared to concrete without fibres. Moreover, fly ash increased the freeze–thaw resistance more than the polypropylene fibres did. Compressive strength decreased with the increase of fly ash content. Influence of polypropylene fibre on compressive strength and elastic modulus is found to be insignificant.

Rao et al.(2011) addresses the flexure and shear behaviour of polypropylene fibre reinforced fly ash concrete(PFRFAC) deep beams. The shear span to depth ratio of the beams used in these investigations was maintained as 2.0. The variables of study include the Characteristic strength of concrete, fck (15.0 MPa, 20.0 MPa, and 25.0 MPa) and polypropylene fibre (Recron 3s) content (0%, 0.5% and 1%). The polypropylene fibre and 20% of Fly ash as cement replacement are incorporated in all the concrete mix proportions considered in this study. The test results indicate that compressive strength of concrete increases with the increasing percentage of fibre. There has been a significant increase in flexural and shear strengths of PFRFAC, in all the mix proportions, as fibre content increased from 0% to 1.0%. However, the ultimate failure was observed to be gradual in all the beams.

Fig 2.5 shows the variation of compressive strength with percentage of polypropylene fibre. The values are normalized with the results of 0% fibre mix. The 28 day compressive strength of fibre reinforced fly ash concrete and normal fly ash concrete are found to match very closely. The 28-day compressive strength of fibre concrete, with fibre contents of 0.5% and 1.0%, increased by 4.42% and 7.74% for concrete of 15.0 MPa characteristic strength, by 3.02% and 4.03% for concrete of 20.0 MPa characteristic strength, and by 2.91% and 8.78% for the concrete of 25.0 MPa characteristic strength respectively, in comparison to the values obtained for normal concrete.

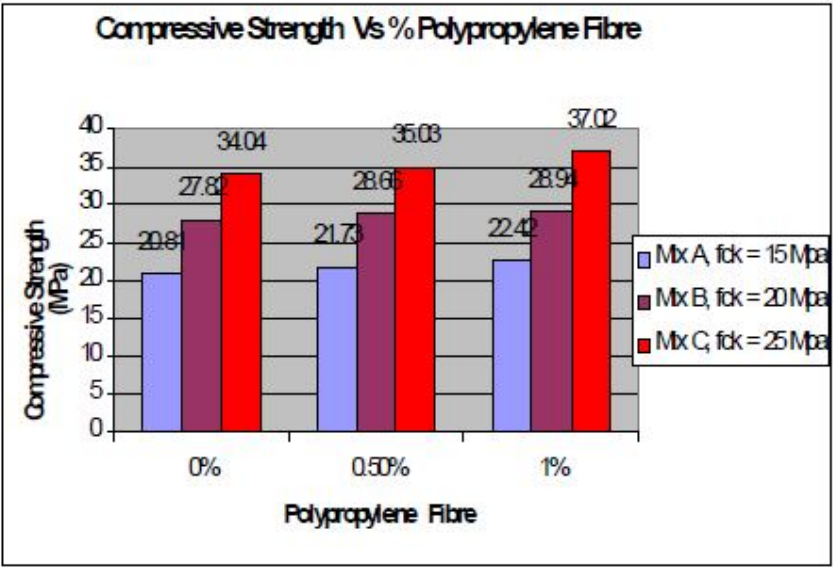


Fig 2.5: shows the variation of compressive strength with percentage of PPF.

Load at first crack in flexures shown in the fig 2.6. The load at first crack of concrete beams is observed to increase with the increased percentage of fibre. With fibre contents of 0.5% and 1%, the increase has been 6.67% and 20% for beams of concrete with 15.0 MPa characteristic strength, 1.85% and 7.01% for beams of concrete with 20.0 MPa characteristic strength and 6.56% and 9.84% for beams with concrete of 25.0MPa characteristic strength respectively, in comparison to the values obtained for normal concretes.

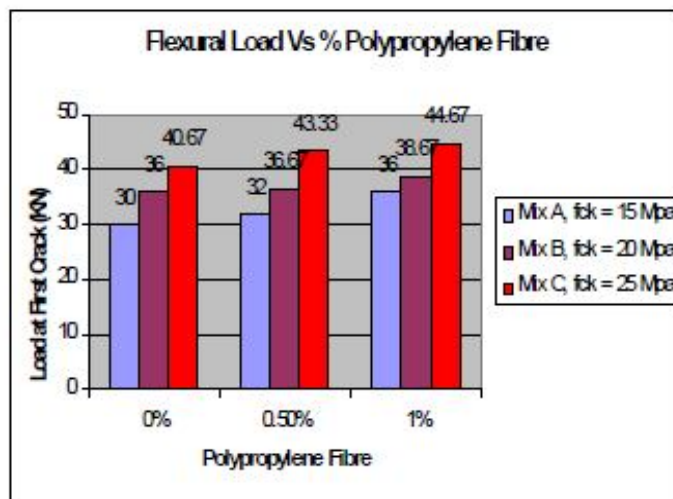


Fig 2.6: shows the variation of first crack in flexure with the variation of PPF.

Patel and Modhera(2011) investigated different concrete mixes containing High Volume Fly Ash concrete was replaced with different percentage of class F fly ash 50,55 and 60%. To improve the engineering properties viz. compressive, flexural, impact strength and abrasion resistance 12mm triangular shaped polyester fibre was used at rate of 0.25% by the mass of cementitious material. For each batching of the sample and design mix the slump values were measured after 60 min retention period using standard slump cone and results were confirmed as per BIS: 456-2000. For compression strength standard 150mm cube were casted to measure strength at 3, 7, 28 and 56 days. Sample were casted and tested as per BIS 516 Comparative study was made for strength development for different dose of flyash as well as with inclusion of 12mm triangular shaped polyester fibre content i.e. 0.25 . Flexural strength was measured at the age of 14,28 and 56 days for all samples using central

point load over span of 400mm, for specimen size 100x100x500mm. Test procedure was carried out as per BIS-516 and results have been shown in fig 2.7 and fig 2.8

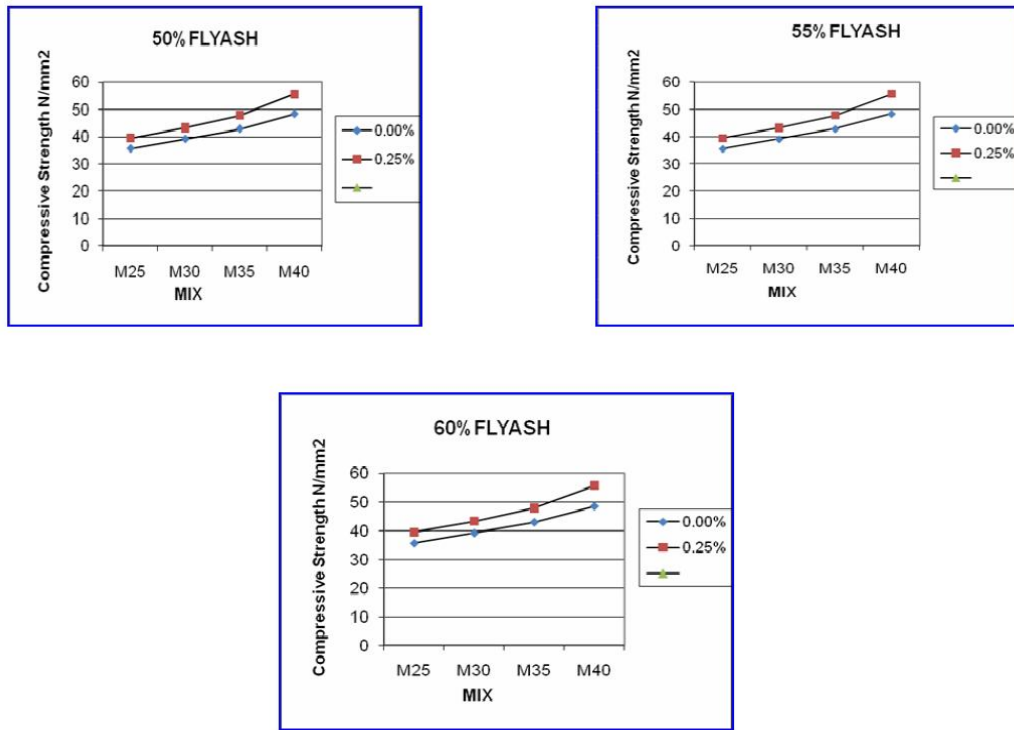


Fig 2.7: Compressive strength(28 days)

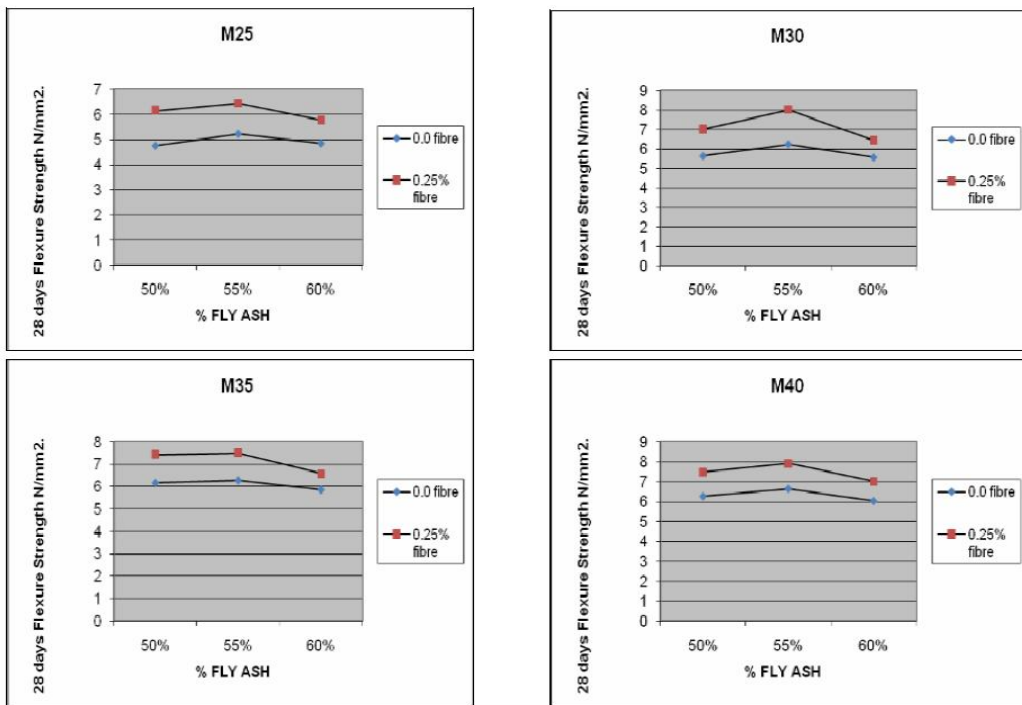


Fig 2.8: Flexural Strength (28 days)

Alsadey S.(2012) studied the effect of superplasticizer (SP) on properties of fresh and hardened concrete ; the properties of concrete inspected are compressive strength and slump test, hence, an experimental investigation conducted to determine the optimum dosage for the admixture and to study the effect of over dosage of the mentioned admixture, together with one control mixed. However, compressive strength is improved by dosage 1.0 % of SP after 28 days curing is 55 N/mm² , which is higher than that of control concrete, the optimum amount of admixture must be 1 %. Over dosage of SP found to deteriorate the properties of concrete with indication of lower compressive strength.

Fig 2.9 shows slump against elapse of different dosages of SP. From the graph, it is clear that slump increase by dosages. However, the SP will help to retain the concrete in liquid state for a longer time, and hence, reduce the slump loss during the transportation of concrete to the site. In addition, over dosage of these admixtures will lead to high slump loss, which will not give true slump that as what we expect and desire.

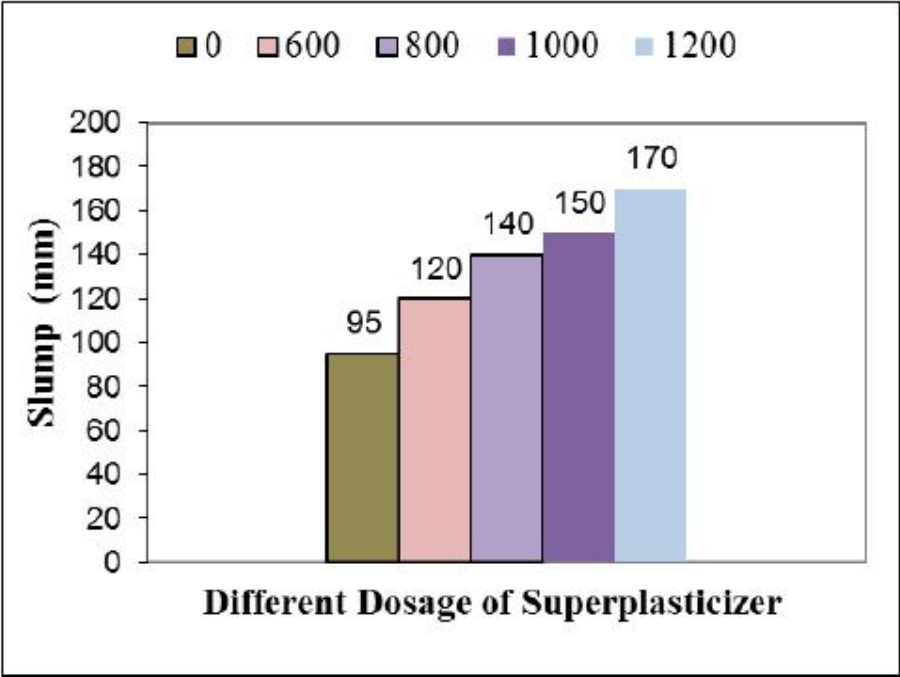


Fig 2.9: Effect of superplasticizer on slump loss

Fig 2.10 shows continuous strength gain for chemical admixture is observed by the increase in compressive strength with increase dosage of superplasticizer, but when we observe the

effect of dosage of the admixture, the admixture present different behaviours on the compressive strength of concrete. Addition of superplasticizer not able to increase the compressive strength of concrete, on the other hand, it reduces the strength significantly, and become worse when the dosages increase.

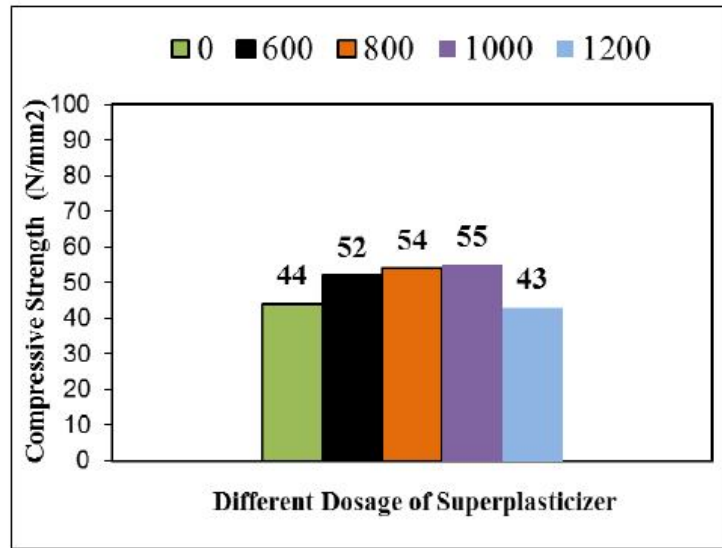


Fig 2.10: Compressive Strength at different dosage of super plasticizer.

Kakoee et al.(2012) properties of polypropylene fibres reinforced concrete such as compressive strength, permeability and electric resistivity of concrete samples were studied. Samples fabricated with coral aggregate and siliceous aggregate were examined and compared. coral aggregate was not a suitable component for concrete structure because of its high electrical resistivity and low compressive strength. The samples with fibres content of 1.5 kg m^{-3} showed optimum results in comparison with other samples in this study.

2.2 Closing Remarks

This chapter highlights the effectiveness of fibres of different types when used in concrete. Different authors have investigated different properties of concrete modified with different fibres and established their effectiveness. It brings out an important observation that fly ash concrete properties are improved by addition of fibres.

3.1 GENERAL

The experimental program consists of investigating compressive strength, split tensile strength and flexural strength of fly ash concrete modified by the use of steel and polypropylene fibers. Cement was replaced with 15%, 20% and 25% of fly ash in concrete. Fly ash concrete was then further modified by using steel and polypropylene fibers in two proportions of 0.5% and 1.0%. The specimens have been classified as control (PC), which denote the plain concrete, steel fibres (SF) and polypropylene fibres (PPF) followed by percentage addition of volume fraction. Experiments programs and Test matrix are outlined in a flow chart in Fig 3.1 below. Nomenclatures for SF and PPF are enlisted in Tables 3.1 and 3.2 respectively.

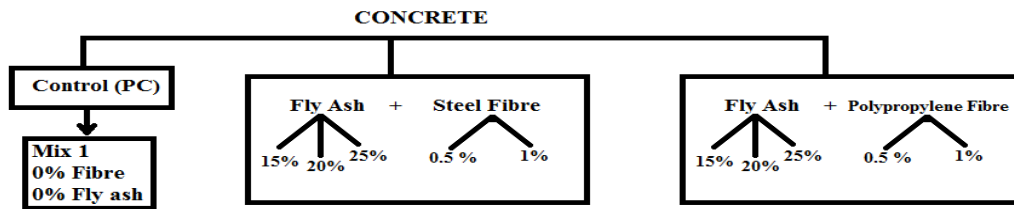


Fig 3.1: Flow chart of experimental programme

Table 3.1: Nomenclature of steel fibres for various mixes

No. of mixes	Nomenclature for mixes with steel fibres
Mix 2	FC 15 SF 0.5
Mix 3	FC 15 SF 1.0
Mix 4	FC 20 SF 0.5
Mix 5	FC 20 SF 1.0
Mix 6	FC 25 SF 0.5
Mix 7	FC 25 SF 1.0

Table 3.2: Nomenclature of polypropylene fibres for various mixes

No. of mixes	Nomenclature for mixes with polypropylene fibres
Mix 8	FC 15 PPF 0.5
Mix 9	FC 15 PPF 1.0
Mix 10	FC 20 PPF 0.5
Mix 11	FC 20 PPF 1.0
Mix 12	FC 25 PPF 0.5
Mix 13	FC 25 PPF 1.0

PC	Plain Concrete
FC15-0.50 SF	Flyash concrete with 15 % flyash and 0.50 % steel fibres.
FC15-1.0 SF	Flyash concrete with 15 % flyash and 1.0 % steel fibres.
FC20-0.50 SF	Flyash concrete with 20 % flyash and 0.50 % steel fibres.
FC20-1.0 SF	Flyash concrete with 20 % flyash and 1.0 % steel fibres.
FC25-0.50 SF	Flyash concrete with 25 % flyash and 0.50 % steel fibres.
FC25-1.0 SF	Flyash concrete with 25 % flyash and 1.0 % steel fibres.
FC15-0.50 PPF	Flyash concrete with 15 % flyash and 0.50 % polypropylene fibres
FC15-1.0 PPF	Flyash concrete with 15 % flyash and 1.0 % polypropylene fibres.
FC20-0.50 PPF	Flyash concrete with 20 % flyash and 0.50 % polypropylene fibres.
FC20-1.0 PPF	Flyash concrete with 20 % flyash and 1.0 % polypropylene fibres.
FC25-0.50 PPF	Flyash concrete with 25 % flyash and 0.50 % polypropylene fibres.
FC25-1.0 PPF	Flyash concrete with 25 % flyash and 1.0 % polypropylene fibres.

In addition to control mix, 12 mixes were prepared and are detailed below:

- 78 cubes (150×150×150 mm) for Compressive strength test
- 39 cylinders(150×300 mm) for Split Tensile Strength test
- 39 beams (700×150×150 mm) for Flexural Strength test

The above details of cubes, cylinders and beams were cast. The details are outlined in Table 3.3 below:

Table 3.3: Tests and Number of specimen

Name of Test	Size of specimen	No. of Mixes	No. of specimens for each mix	Total Number of specimens
Compressive strength test	150×150×150 mm cube	13	6	78
Split Tensile Strength test	150×300 mm cylinder	13	3	39
Flexural Strength test	700×150×150 mm beam	13	3	39

3.2 MATERIALS USED

Cement, fine aggregates, coarse aggregates, fly ash, steel fibres, polypropylene fibres, super-plasticizer and water used throughout the investigation, had the following properties:

3.2.1 CEMENT

Cement is a fine, grey powder. It is mixed with water and materials such as sand, gravel, and crushed stone to make concrete. The cement and d water form a paste that binds the other materials together as the concrete hardens. The ordinary cement contains two basic ingredients namely argillaceous and calcareous. In argillaceous materials clay predominates and in calcareous materials calcium carbonate predominates. Ordinary Portland cement of grade – 43 (Ultra tech cement) conforming to Indian standard IS: 8112-1989 has been used in the present study. The results of the various tests on cement properties are given in Table 3.4.

Table 3.4: Physical properties of Portland cement.

S. No.	Characteristics	Values obtained	Standard values
1.	Normal Consistency	29.5%	-
2.	Initial setting time	1 hours 55 min	Not to be less than 30 minutes
3.	Final Setting time	3 hours 40 min	Not to be greater than 600 minutes
4.	Fineness	2.5%	<10%
5.	Specific gravity	3.38	-
Compressive strength (MPa)			
1.	3 days	23.75	23
2.	7 days	34.183	33
3.	28 days	44.15	43

3.2.2 FLY ASH

Fly ash is a fairly divided residue which results from the combustion of ground or powdered bituminous coal or sub bituminous coal like lignite. It is a byproduct of many thermal power stations. Fly ash resembles pozzolana i.e. a substance which although not cementitious itself contains constituents which combine with lime to form a material having cementitious properties. It is acidic in nature and its main constituents are silica, aluminium oxide and ferrous oxide. Fly ash used in the study has been obtained from **Lehra Mohobbat thermal power plant, District Bathinda**. Its properties are given in Table 3.5.

Table 3.5: Physical and chemical properties of Fly ash used.

Physical Properties	Value
Colour	Whitish grey to grey with slight black
Bulk density	1120 kg / m ³
Specific gravity	2.14 to 2.42
Fineness	2800 to 3200 cm ² /gm
Chemical Properties	Value
Constituent	Weight%
Silica (SiO ₂)	40 to 79
Alumina (Al ₂ O ₃)	23 to 33
Ferric Oxide (Fe ₂ O ₃)	0.6 to 4
Calcium Oxide (CaO)	2.8 to 20
Magnesia (MgO)	1.5 to 5.0
Ignition Loss	1.0 to 3.0

3.2.3 FINE AGGREGATES

The material which passes through BIS test sieve no. 480 is termed as fine aggregate. Usually natural sand is used as a fine aggregate at places where natural sand is not available crushed stone is used as a fine aggregate.

The sand used for the experimental works was locally procured and conformed to grading zone III. Sieve Analysis of the Fine Aggregate was carried out in the laboratory as per IS 383-1970 and results are provided in Table 3.6. The sand was first sieved through 4.75 mm sieve to remove any particle greater than 4.75 mm sieve and then was washed to remove the dust. The physical properties are provided in Table 3.7

Table 3.6 Sieve Analysis of fine aggregates.

S. No.	Sieve No.	Weight Retained (gms)	Percentage Retained%	Percentage Passing %	Cumulative % Retained
1.	4.75 mm	95	9.5	90.5	9.5
2.	2.36 mm	42.5	4.25	86.25	13.75
3.	1.18 mm	110.5	11.05	75.2	24.8
4.	600 mm	128.5	12.85	62.35	37.65
5.	300 mm	308.0	30.8	31.55	68.45
6.	150 mm	281.0	28.1	3.45	96.55
7.	Pan	34.5	3.45	----	----
				$\Sigma F =$	250.5

$$\text{Fineness Modulus of fine aggregate} = \Sigma F/100 = 250.5/100=2.50$$

Table 3.7 Physical properties of fine aggregates

S. No.	Characteristics	Value
1.	Type	Natural Sand
2.	Specific Gravity	2.65
3.	Fineness Modulus	2.505
4.	Grading Zone	III

3.2.4 COARSE AGGREGATES

The material which is retained on BIS test sieve no. 480 is termed as a coarse aggregate. The broken stone is generally used as a coarse aggregate. The nature of work decides the maximum size of the coarse aggregate. Locally available coarse aggregate having the maximum size of 20 mm was used in the present work. Sieve analysis of coarse aggregates used was carried out and results are provided in table 3.8. The physical properties of coarse aggregates used are provided in table 3.9.

Table 3.8 Sieve Analysis of coarse aggregates

S. No.	Sieve No.	Weight Retained (gms)	Percentage Retained%	Percentage Passing %	Cumulative % Retained
1.	80mm	-----	0.00	100	0.00
2.	40mm	-----	0.00	100	0.00
3.	20mm	0	0.00	100	0.00
4.	12.5mm	2186.5	72.883	27.117	72.883
5.	10mm	674.5	22.483	4.634	95.336
6.	4.75mm	139.0	4.633	0.01	99.999
7.	Pan	0	0.00	----	----
				$\Sigma C =$	268.24

Fineness Modulus of coarse aggregates (20mm) = $\Sigma C + 500/100 = 268.24 + 500/100 = 7.68$

Table 3.9 Properties of coarse aggregates

S. No.	Characteristics	Value
1.	Type	Crushed
2.	Specific Gravity	2.61
3.	Water absorption	2.37%
4.	Fineness Modulus	7.68
5.	Maximum Size	20mm

3.2.5 STEEL FIBRES

Mild steel fibres having 35 mm length and 0.75 mm average thickness i.e. having aspect ratio 50 which are corrugated and obtained through cutting of steel wires have been used. The fibres have been cut by fiber cutting machine to an accurate size. Two different proportions of fibres (0.50, and 1.0 %) have been used. Properties of steel fiber used are tabulated in Table 3.10.

Table 3.10: Physical properties of steel fiber

Average Thickness	0.75
Length, mm	35
Density	7850 kg / m ³
Tensile strength	8500 kg / cm ²
Specific gravity	7.85

3.2.6 POLYPROPYLENE FIBRES

Recron 3s fibre (CT-2024) is a fibre developed after extensive research at Reliance Technology Centre. CT-2024 is monofilament fibre designed specially to provide integral secondary reinforcement of concrete. Recron 3s fibres are Polyester staple fibres mainly used for mixing in concrete and mortar for improving certain properties of the concrete and mortar.

The Fibres have special triangular shape for better anchoring with other ingredients of the mix. The fibres are made from polymerization of pure terephthalic acid and Mono Ethylene Glycol using catalyst. Recron 3s fibres are available in 6mm and 12mm length. In our research work fibre dosage was fixed as .5% per bag of cement. The properties of Recron 3s Fibres are provided in Table 3.11.

Table 3.11: Properties of Recron 3s fibres (CT 2.24)

S. No.	Specifications	Value
1.	Material	100% Virgin Polyester
2.	Filament Diameter	3.-35 microns
3.	Cut Length	12mm
4.	Tensile strength	600kg/cm ²
5.	Melting point	>250 ⁰ C
6.	Dispersion	Excellent
7.	Acid resistance	Good
8.	Alkali resistance	Good
9.	Electrical Conductivity	Low
10.	Thermal Conductivity	Low

Reference: Chart provided by Reliance industries for Recron 3s fibres on their website (www.ril.com).

3.2.7 WATER

Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. Since it helps to form the strength giving cement gel, the quantity and quality of water is required to be looked into very carefully. Potable water is generally considered satisfactory. In the present investigation, tap water was used for both mixing and curing purposes. According to IS: 456-2000, water for concrete should be of potable quality (PH-6.8 to 8.0). Ordinary tap water, which is fit for drinking, have been used in preparing all concrete mixes and curing in this investigation.

3.2.8 SUPERPLASTICIZER

Sika Visco Crete -SC 001, the superplasticizer supplied by Sika India Pvt. Limited was used in investigations. It is a third generation highly effective superplasticizer for concrete and mortar. It meets the requirements for superplasticizer according to EN934 -2, SIA 262, ASTM C 494-99/99a Type F and 9103-1999 (amended 2003). The dosage of the superplasticizer was fixed based on the requirements for workability. The technical data related to the superplasticizer used is provided in Table 3.12.

Table 3.12: Technical data of Super plasticizer

(Literature provided with Super plasticizer)

S. No.	Characteristic	Value
1.	Colour	Dark brown liquid
2.	Specific gravity	1.17
3.	Air Entrainment	Maximum 1%
4.	pH	7 to 8

3.3 CONCRETE MIX DESIGN

M 25 was designed using the IS code mix design method. Procedure and details of mix design are detailed below:

Design for M25 mix as per IS: 10262-2009

Characteristic compressive strength, f_{ck}	=	25 N/mm ²
Degree of quality control	=	Good
Type of exposure	=	Mild
Degree of workability	=	High
(i) Slump	=	60-180 mm
(ii) Vee-Bee	=	0-3 sec.
Type of cement	=	OPC
Max. Aggregate size	=	20 mm
Specific gravity of cement	=	3.38
Specific gravity of fine aggregate	=	2.65
Specific gravity of coarse aggregate	=	2.61
F. M. of fine aggregate	=	2.50
Grading zone of fine aggregates as	=	Zone III

per IS: 383-1970

(i) Target Mean Strength

The target mean strength (f_t) is determined by using the relation:

$$f_t = f_{ck} + K.S$$

Where f_{ck} is the characteristic compressive strength at 28 days, S is standard deviation and K is statistical coefficient. For the definition of characteristic strength given in IS: 456– 2000, $K = 1.65$.

$S = 5.3$ for M25 mix and good degree of control

$$f_t = 25 + 1.65 \times 5.3$$

$$f_t = 33.75 \text{ N/ mm}^2$$

(ii) Selection of water – cement Ratio

The water cement ratio for target mean strength is chosen as 0.45.

(iii) Selection of water and sand content

From Table 2 of IS:10262-2009, maximum water content for 20 mm. aggregate = 186 litres. Sand content as percentage of total aggregate by absolute volume for water cement 0.42= 35%. Therefore applying corrections from IS:10262-2009 according to which (aggregate content should be decreased at a rate of 0.01 for every 0.05 increase in water cement ratio).

Therefore respectively, kg before sand content comes out to be 32%.

(iv) Cement Content

$$w/c \text{ ratio} = 0.45$$

$$\text{Water content} = 186 \text{ kg/cu.m}$$

$$\text{Cement content} = 186/0.45 = 413.33 \text{ kg/cu.m}$$

(v) Determination of Proportion of Fine Aggregates and Coarse Aggregates

For 20 mm nominal size aggregates, entrapped air is 2%.

Fine Aggregate,

$$V = [W + C/S_c + \{ 1 / (p * f_a / S_{fa}) \}] / 1000$$

Where V= absolute volume of fresh concrete= gross volume(1m^3) minus the volume of entrapped air.

S_c = specific gravity of cement

W= Mass of water per cubic metre of concrete, kg

C= mass of cement per cubic metre of concrete, kg

P= ratio of fine aggregate to total aggregate by absolute volume,

f_a = total mass of fine aggregate per cubic metre of concrete

S_{fa} = specific gravity of saturated surface dry fine aggregates.

$$0.98 = [186 + 413.33 / 3.12 + \{ (1/0.32 * f_a / 2.54) \} * 1/1000$$

On solving the above equation, we get

$$f_a = 537.83 \text{ kg/cu.m}$$

Coarse Aggregate,

$$V = [W + C/S_c + \{ 1 / (1-p) * c_a / S_{c_a} \}] / 1000$$

Where

C_a = total mass of coarse aggregates per cubic metre of concrete

S_{c_a} = specific gravity of saturated surface dry coarse aggregates.

$$0.98 = [186 + 413.33 / 3.12 + \{ (1/0.68 * c_a / 2.64) \} * 1/1000$$

On solving the above equation, we get

$$C_a = 1202.78 \text{ kg/cu.m}$$

Table 3.13: Mix design proportions (w/c=0.45)

Cement(kg/cu.m)	Sand(kg/cu.m)	Coarse Aggregates(kg/cu.m)
413.33	537.83	1202.78
1	1.3	2.9

The proportions for concrete are determined as 1:1.6:2.9 by weight with w/c ratio of 0.45. 12 mixes having combinations of various percentages of fly ash and fibres and 1 control mix was prepared.

3.4 Concrete Mix Proportions

The proportions of various constituents of concrete of all mixes i.e. for cube, beam and cylinder specimens has been detailed in Tables 3.14, 3.15 and 3.16.

Table 3.14: Mixture proportions for 1 cube specimen

Mix designation	FC (Kg)	Fibres (Gms)	Cement (Kg)	Sand (Kg)	NA (Kg)	Water (Litres)	Superplasticizer (% by wt of cement)
Mix 1	0	0	1.53	2.0	4.45	0.68	0
Mix 2/8	0.23	7.65	1.30	2.0	4.45	0.68	24.90
Mix 4/10	0.31	7.70	1.23	2.0	4.45	0.68	22.08
Mix 6/12	0.38	7.65	1.15	2.0	4.45	0.68	20.70
Mix 3/9	0.23	15.3	1.30	2.0	4.45	0.68	24.90
Mix 5/11	0.31	15.4	1.23	2.0	4.45	0.68	22.08
Mix 7/13	0.38	15.3	1.15	2.0	4.45	0.68	20.70

Table 3.15: Mixture proportions for 1 cylinder specimen

Mix designation	FC (kg)	Fibres (Gms)	Cement (Kg)	Sand (Kg)	NA (Kg)	Water (Litres)	Superplasticizer (% by wt of cement)
Mix 1	0	0	2.41	3.14	7.0	1.07	0
Mix 2/8	0.36	12	2.04	3.14	7.0	1.07	6.12
Mix 4/10	0.48	12	1.92	3.14	7.0	1.07	5.76
Mix 6/12	0.60	12	1.80	3.14	7.0	1.07	5.42
Mix 3/9	0.36	24	2.04	3.14	7.0	1.07	6.12
Mix 5/11	0.48	24	1.92	3.14	7.0	1.07	5.76
Mix 7/13	0.60	24	1.80	3.14	7.0	1.07	5.42

Table 3.16: Mixture proportions for 1 Beam specimen

Mix designation	FC (kg)	Fibres (Gms)	Cement (Kg)	Sand (Kg)	NA (Kg)	Water (Litres)	Superplasticizer (% by wt of cement)
Mix 1	0	0	7.15	9.25	20.79	3.22	0
Mix 2/8	1.08	35.78	6.08	9.25	20.79	3.22	18.24
Mix 4/10	1.43	35.75	5.72	9.25	20.79	3.22	17.16
Mix 6/12	1.79	35.75	5.36	9.25	20.79	3.22	16.08
Mix 3/9	1.08	71.57	6.08	9.25	20.79	3.22	18.24
Mix 5/11	1.43	71.50	5.72	9.25	20.79	3.22	17.16
Mix 7/13	1.79	71.50	5.36	9.25	20.79	3.22	16.08

3.5 Mixing, Compaction and Curing

3.5.1 Mixing

After weighting accurately cement, sand and coarse aggregate, these have been mixed dry to get uniform colour. Proper mixing of flyash and cement has been ensured before adding to the mix. Fibers have been mixed by sprinkling them with the hand while mixing in such manner that fibers are distributed uniformly throughout. Water has been added to mix and proper mixing is ensured. Balling or lump formation if found anywhere has been loosened to achieve a homogeneous mix.

3.5.2 Compaction

For compacting fibre reinforced concrete usual methods of mechanical vibration such as obtained in a needle or table vibrator, can be used. Needle vibration however, is not preferred with higher volume content of fibres, as the holes left by the needle may remain unfilled due to interlocking effect of the fibres. Table vibrator is the most suitable as it gives the advantages of fibres acquiring a tendency to align themselves in a plane perpendicular to the direction of vibration. This results in random planer orientation. A fibre mix generally requires somewhat greater vibration to move the mix and consolidate it into the moulds. The compaction of the specimens has been done on a platform vibrating table.

3.5.3 Curing

Identification marks have been engraved into the specimens after 4 –5 hour of casting. They are allowed to set in the moulds for 24 hours after which they have been taken out of the moulds and immersed in fresh water for curing for a specified period of times. The specimens have been then removed from water and stored in a room till their time of testing.

3.7 Testing of specimens

In the present research, specimens have been tested under the 3000 KN capacity Automatic Compression Testing Machine (ACTM). All the three tests of compressive strength, split tensile strength and flexural strength were carried out for all the mixes. This machine fulfills all the requirement for compression testing as per IS: 516-1959. Specimens stored for curing have been tested immediately on removal from the water, while they are in the wet condition. Surface water and grit has been wiped off the specimens. The bearing surfaces of the testing machine also have been wiped clean and any loose sand or other material is removed.

Compressive strength test

Cube specimens have been placed centrally in the machine in such a manner that the load is applied to opposite sides of the cubes as cast, that is not to the top and bottom. The load is applied in a continuous and uniform fashion without shock with the help of computer attached to the machine at a pace rate of approximately 5.0 KN/s automatically. Thus, the specimens have been tested under stress control loading. The compressive strength is obtained by the formula as given below and the specimen tested is shown in fig 3.1.

$$\sigma = P/A$$

where P = load at which the cube specimen fails (in KN)

A= cross-sectional area of cube which is 150*150mm².



Fig 3.2 Cube specimen subjected to compression

Split tensile strength test

The splitting tests are well known indirect tests used for determining the tensile strength of concrete sometimes referred to as split tensile strength of concrete. The test consists of applying a compressive line load along the opposite generators of a concrete cylinder placed with its axis horizontal between the compressive platens. Due to the compression loading a fairly uniform tensile stress is developed over nearly 2/3 of the loaded diameter as obtained from an elastic analysis. The magnitude of this tensile stress f_{sp} (acting in a direction perpendicular to the line of action of applied loading) is given by the formula (IS: 5816-1970) and is calculated below and its testing is shown in fig 3.2

$$f_{sp}(\text{split tensile strength}) = \frac{2P}{\pi dl} = 0.637 \frac{P}{dl}$$

where

P= load at which the specimen fails (in KN)

d= diameter of cylinder specimen (in mm)

l= length of cylinder specimen (in mm)

The ratio of the split tensile strength to cylinder strength not only varies with the grade of the concrete but is also dependent on the age of concrete. This ratio is found to decrease with time after about a month. The air-cured concrete gives lower tensile strength than that given by moist-cured concrete.



Fig 3.3: Cylinder specimen subjected to split tensile strength

Flexural strength test

The flexural strength test of beam, a specimen of size 700*150*150mm is placed over two point loading arrangement and the stresses produced during breakage of specimen. The flexural strength is reported as Modulus of Rupture f_t (N/mm^2) and is calculated as

$$f_t = PL/bd^2 .$$

where P = Load at which the beam specimen fails (in KN)

L = effective length of the beam specimen (in mm)

b = width of the beam specimen (in mm)

d = depth of the beam specimen (in mm).



Fig 3.4 Beam specimen subjected to two point loading

3.8 Closing Remarks

This chapter outlines the detailed experimental program conducted in this research attempt. Details of the test matrix along with test details are also explained in this chapter.

4.1 General

This chapter includes the test results in which fly ash is used as a replacement material (15%,20%,25%) with cement and addition of steel fibres (average thickness 0.75mm) and polypropylene fibres (12mm). It is done to obtain the desired compressive strength, split tensile strength and flexural strength of concrete lost by addition of fly ash. Mix design used in the test is M-25 and water-cement ratio is kept constant throughout i.e. 0.45.

It is evident that the addition of fly ash as the replacement of cement reduces the compressive strength of plain concrete. When some types of fly ash replaces with cement in concrete mixture, fresh concrete workability is increased, early strength and shrinkage of hardened concrete are decreased , and permeability is decreased due to filling the micropores of concrete. All these variations on concrete properties, caused by fly ash, depend on the mineralogical composition and fines of fly ash. In this work, strength properties of fly ash concrete modified by addition of steel and polypropylene fibres are studied to investigate whether the strength lost by addition of fly ash can be retrieved by addition of small amount of fibres.

As fly ash inclusion in concrete mix decreases its strength, so in order to compensate the strength steel fibres of length 35 mm and average thickness of 0.75 mm which are used in this study are added to concrete mix at a volume fraction of 0.5% and 1.0%. Also polypropylene fibres of cut length 12mm are used in the study. The effect of steel fibres and polypropylene fibres on compressive strength, split tensile strength and flexural strength are discussed in detail below:

4.2 Effect of steel fibres on compressive strength

The effect of steel fibres on compressive strength of concrete at 7 and 28 days and the graphical representation of results are detailed below in Tables 4.1 and 4.2 and fig 4.1 and 4.2 respectively.

Table 4.1: Compressive strength variation in 7 days of FASFRC

Type of Mix	Compressive strength, (Mpa)	Ratio FC/PC	Percentage Improvement w.r.t PC
Mix 1	21.84	-	-
Mix 2	28.44	1.164	23.21
Mix 3	34.25	1.568	36.23
Mix 4	27.53	1.260	20.67
Mix 5	31.95	1.463	31.64
Mix 6	23.38	1.070	6.58
Mix 7	29.38	1.090	8.27

Table 4.2: Compressive strength variation in 28 days of FASFRC

Type of Mix	Compressive strength, (Mpa)	Ratio FC/PC	Percentage Improvement w.r.t PC
Mix 1	33.47	-	-
Mix 2	36.99	1.10	9.51
Mix 3	43.49	1.30	23.04
Mix 4	37.13	1.12	9.86
Mix 5	41.08	1.23	18.52
Mix 6	34.16	1.02	2.02
Mix 7	35.11	1.05	4.67

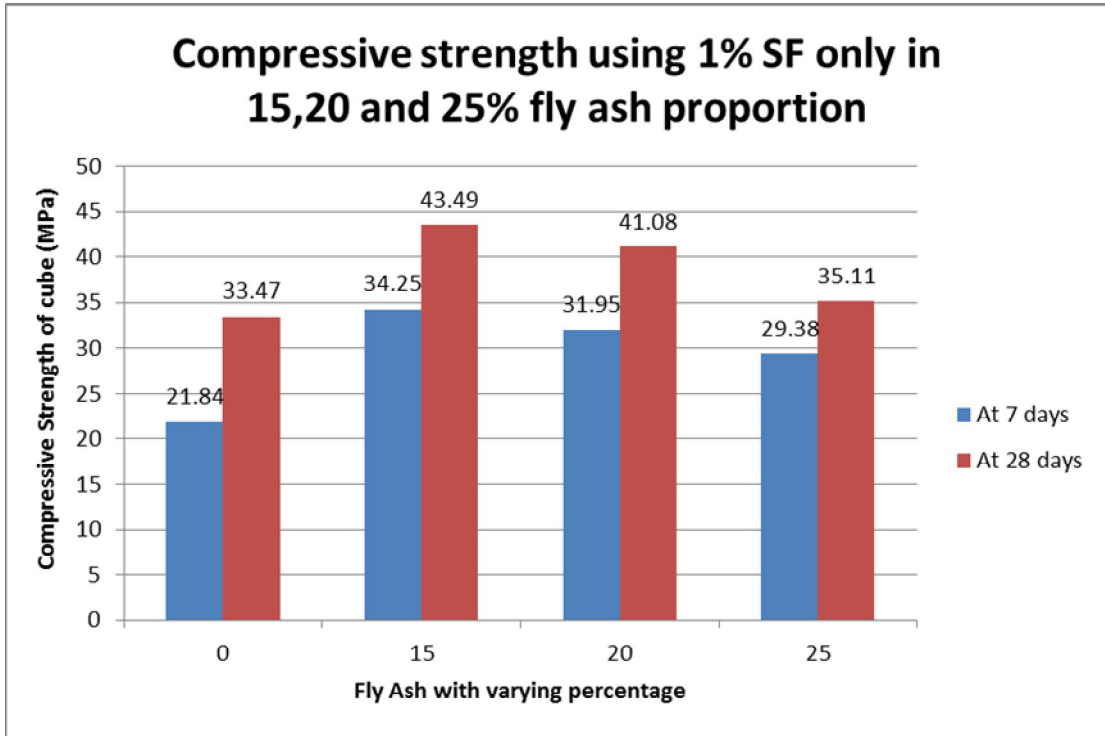


Fig 4.1 Showing compressive strength of cube using 1% steel fibre at 7 and 28 days with varying percentage of fly ash.

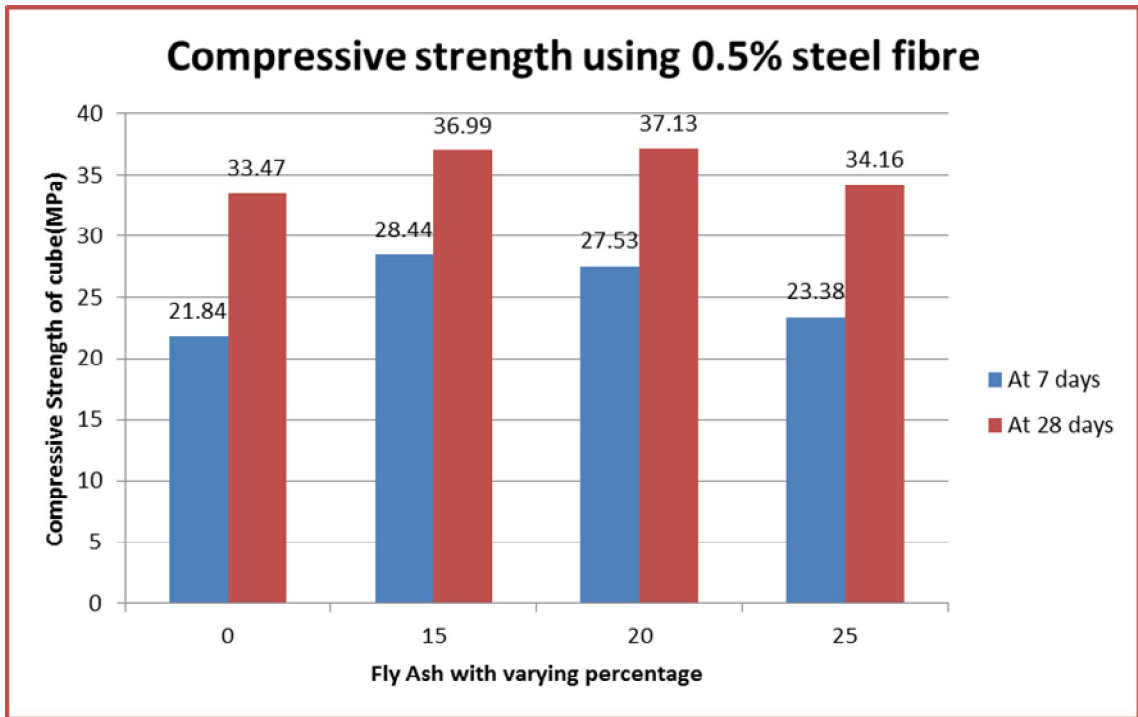


Fig 4.2 Showing compressive strength using 0.5%SF at 7 and 28 days with varying percentage of fly ash.

From these compressive strength results of SFRC following observations are made:

- Both 7 days as well as 28 days compressive strength of fly ash concrete modified by steel fibres is higher than plain concrete irrespective of percentage of fly ash.
- When the percentage of fly ash increases from 15% to 25%, increase in strength of concrete modified by the addition of steel fibres reduces.
- At 7 days compressive strength, as the percentage of fly ash increases the strength of concrete containing steel fibres decreases. The percentage increase in strength with 15% fly ash is more when fibre content is increased from 0.5% to 1.0% while the least percentage increase is observed in case of 25% fly ash. When the fibre content increases from 0.5% to 1.0%, the percentage improvement is 35.93, 34.67 and 20.43 in case of 15%, 20% and 25% fly ash replacement respectively.
- At 28 days compressive strength, with the increase in fibre content from 0.5% to 1.0%, the percentage improvement in strength w.r.t plain concrete is 58.72, 46.76 and 37.83 in case of 15%, 20% and 25% fly ash replacement respectively.

4.3 Effect of steel fibre on split tensile strength

The effect of steel fibres on split strength of concrete at 28 days and the graphical representation of results are detailed below in Table 4.3 and fig 4.3 respectively.

Table 4.3: Split tensile strength variation in 28 days of FASFRC.

Type of Mix	Split Tensile strength, (Mpa)	Ratio FC/PC	Percentage Improvement w.r.t PC
Mix 1	5.46	-	-
Mix 2	7.81	1.43	30.09
Mix 3	9.08	1.66	39.87
Mix 4	11.09	2.03	50.77
Mix 5	11.18	2.05	51.16
Mix 6	9.69	1.77	43.65
Mix 7	10.71	1.96	49.02

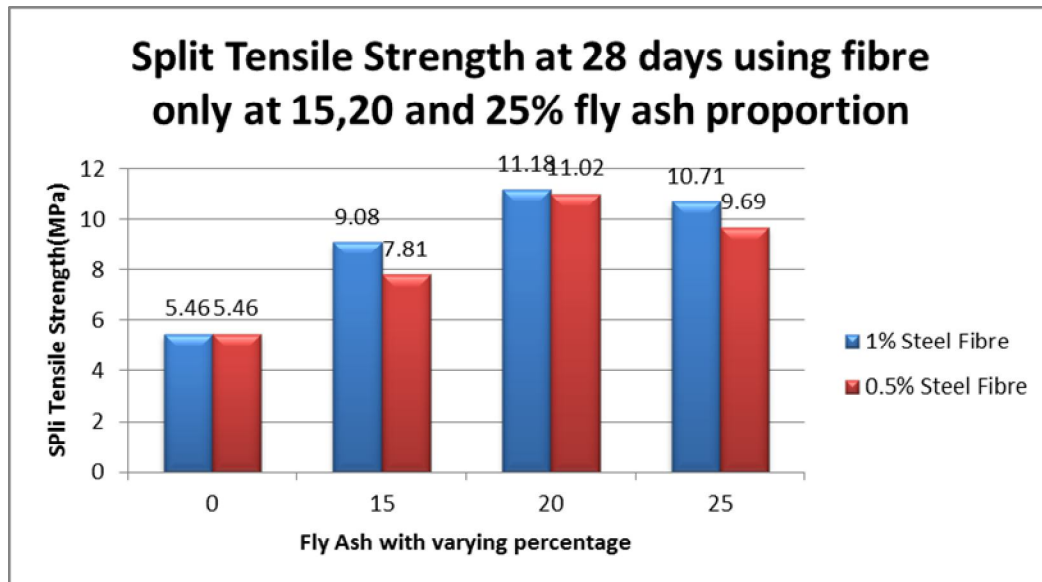


Fig 4.3 Showing splitting tensile strength at curing period of 28 days using 1 and 0.5% steel fibres with varying percentage of fly ash.

From the split tensile strength results given above, the following observations have been done

- The split tensile strength of plain concrete at 28 days comes out to be 5.46 MPa. For 0.5% dosage of fibre with three replacement ratios of fly ash i.e. 15%, 20% and 25%, the percentage improvement in cylindrical strength at 28 days comes out to be 30.09, 50.77 and 43.65 respectively. For 1.0% addition of fibres and with similar fly ash replacement ratios, the percentage improvement in strength is 39.87, 51.16 and 49.02 respectively.
- With the percentage increment of fly ash, split tensile strength decreases but when with the same fly ash content if fibre addition is increased from 0.5% to 1.0%, the strength increases.
- More improvement is seen in case of 20% fly ash with 1% steel fibre while the least is seen in case of 25% fly ash and 0.5% steel fibre.

4.4 Effect of steel fibre on flexural strength

The effect of steel fibres on flexural strength of concrete at 28 days and the graphical representation of results are detailed below in Table 4.4 and fig 4.4 respectively.

Table 4.4: Flexural strength variation in 28 days FASFRC

Type of Mix	Flexural Tensile strength, (Mpa)	Ratio FC/PC	Percentage Improvement w.r.t PC
Mix 1	7.48	-	-
Mix 2	10.79	1.44	30.68
Mix 3	11.13	1.49	32.79
Mix 4	12.64	1.69	40.82
Mix 5	14.42	1.93	48.13
Mix 6	8.56	1.14	12.62
Mix 7	13.58	1.81	44.91

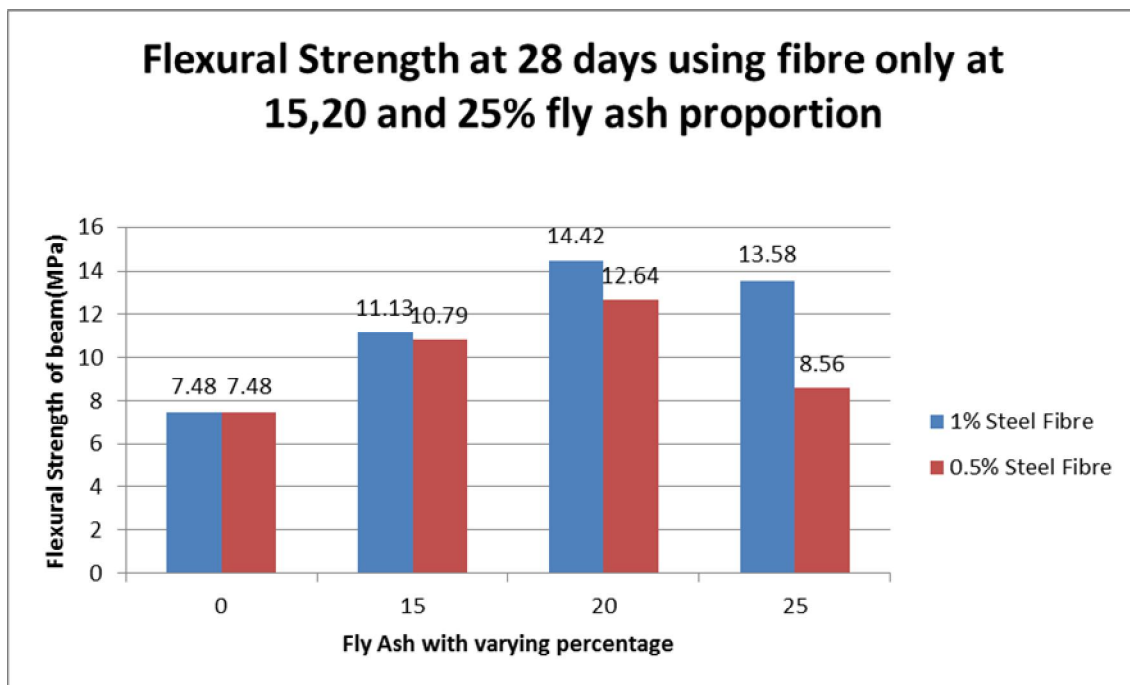


Fig 4.4 Showing flexural strength at curing period of 28 days using 1 and 0.5% steel fibre at varying percentage of fly ash.

From the above table and graph of flexural strength, following observations have been made.

- The flexural strength of plain concrete at 28 days is 7.48 MPa. For 0.5% fibre addition with 15%, 20% and 25% fly ash replacement, the percentage improvement is of the order 30.68, 40.82 and 12.62 respectively. For 1.0% fibre addition with same replacement of fly ash, the percentage improvement is of the order 32.79, 48.13 and 44.91 respectively.
- With the percentage increment of fly ash, split tensile strength decreases but when with the same fly ash content if fibre addition is increased from 0.5% to 1.0%, the strength increases.
- More improvement is seen in case of 20% fly ash with 1% steel fibre while the least is seen in case of 25% fly ash and 0.5% steel fibre.

4.5 Effect of polypropylene fibres on compressive strength

The effect of polypropylene fibre on compressive strength of concrete at 7 and 28 days have been discussed in Tables 4.5 and 4.6 respectively while their results have been graphically represented in fig 4.5 and 4.6.

Table 4.5: Compressive strength variation in 7 days of FAPPFRC

Type of Mix	Compressive strength, (Mpa)	Ratio FC/PC	Percentage Improvement in strength w.r.t PC
Mix 1	21.81	-	-
Mix 8	27.05	5.24	19.37
Mix 9	34.06	12.25	35.96
Mix 10	22.84	1.03	4.51
Mix 11	28.28	6.47	22.87
Mix 12	22.25	0.44	1.98
Mix 13	22.82	1.01	4.42

Table 4.6: Compressive strength variation in 28 days of FAPPFRC

Type of Mix	Compressive strength, (Mpa)	Ratio FC/PC	Percentage Improvement in strength w.r.t PC
Mix 1	33.47	-	-
Mix 8	34.02	0.55	1.62
Mix 9	37.10	1.11	9.78
Mix 10	36.83	1.10	9.12
Mix 11	37.40	1.12	10.51
Mix 12	33.81	1.01	1.01
Mix 13	34.97	1.04	4.29

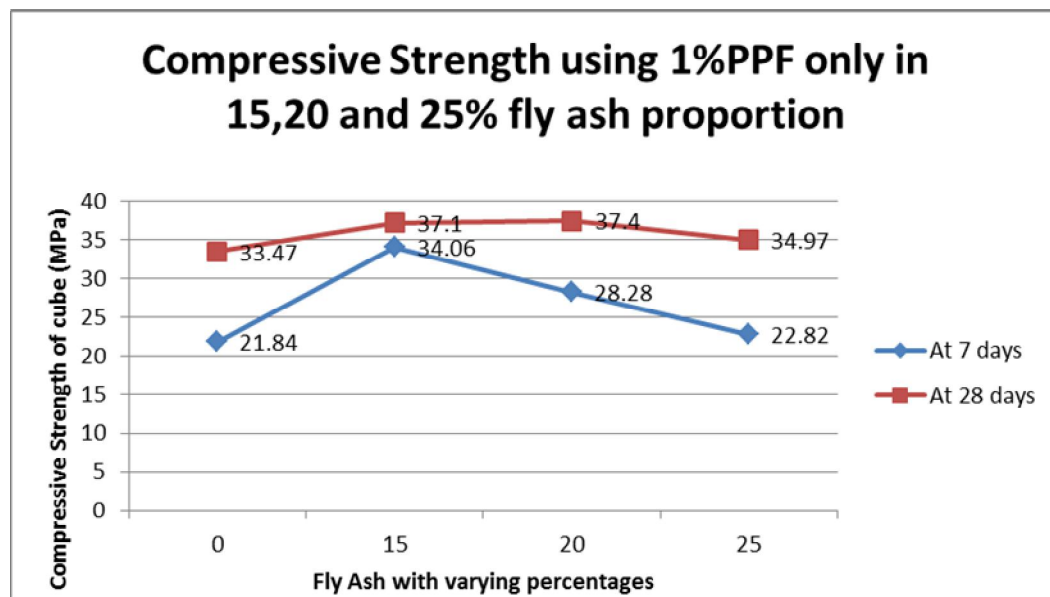


Fig 4.5 Showing the compressive strength of cubes using 1%PPF at 7 and 28 days respectively with varying percentages of fly ash.

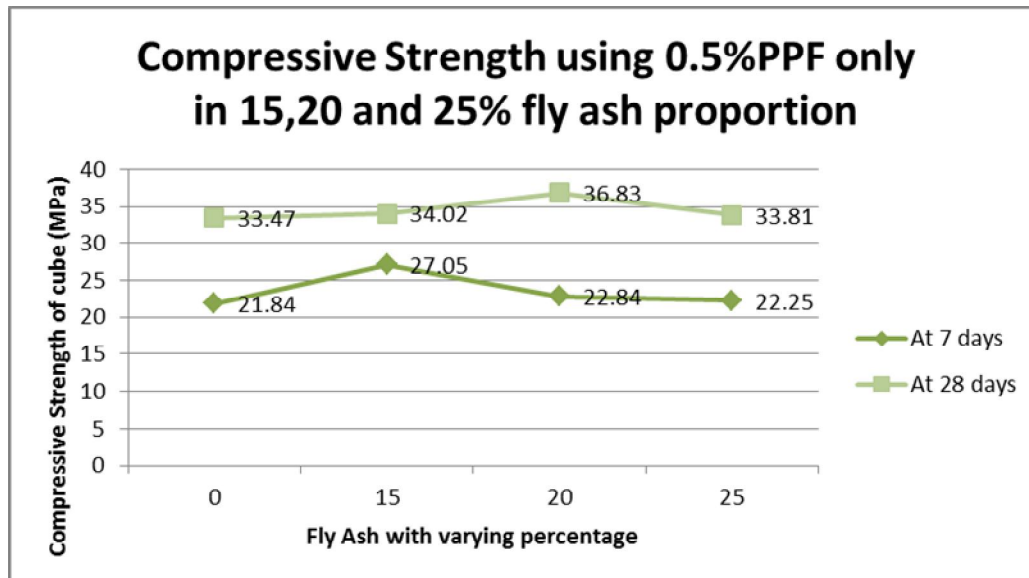


Fig 4.6 Showing compressive strength using 0.5%PPF at 7 and 28 days respectively with varying percentages of fly ash.

From these compressive strength results of FAPPFRC the following observations are made:

- Both 7 days as well as 28 days compressive strength of fly ash concrete modified by polypropylene fibres is higher than plain concrete irrespective of percentage of fly ash.
- When the percentage of fly ash increases from 15% to 25%, increase in strength of concrete modified by the addition of polypropylene fibres reduces.
- At 7 days compressive strength and fibre content of 0.5% volume fraction and cement replacement with fly ash by 15%, 20% and 25% ratios, the percentage improvement in strength is of the order 19.37, 4.51 and 1.98 respectively. For same fly ash replacement ratio, when fibre is added at 1.0% volume fraction, the percentage improvement in strength is of the order 35.96, 22.87 and 4.42 respectively.
- At 28 days compressive strength with 0.5% fibre dosage with the replacement of fly ash as 15%, 20% and 25%, the percentage improvement in strength is 1.62, 9.12 and 1.01 respectively. For 1.0% fibre dosage and same fly ash replacement ratios, the percentage improvement is of the order 9.78, 10.51 and 4.29 respectively.

4.6 Effect of Polypropylene fibre on split tensile strength

The effect of polypropylene fibres on split strength of concrete at 28 days and the graphical representation of results are detailed below in Table 4.7 and fig 4.7 respectively.

Table 4.7: Split tensile strength variation at 28 days of FAPPFRC

Type of Mix	Split Tensile strength, (Mpa)	Ratio FC/PC	Percentage Improvement w.r.t PC
Mix 1	6.42	-	-
Mix 8	6.77	0.35	5.17
Mix 9	7.78	1.36	17.48
Mix 10	7.36	0.94	12.77
Mix 11	8.34	1.92	23.02
Mix 12	6.54	0.12	1.83
Mix 13	7.98	1.56	19.55

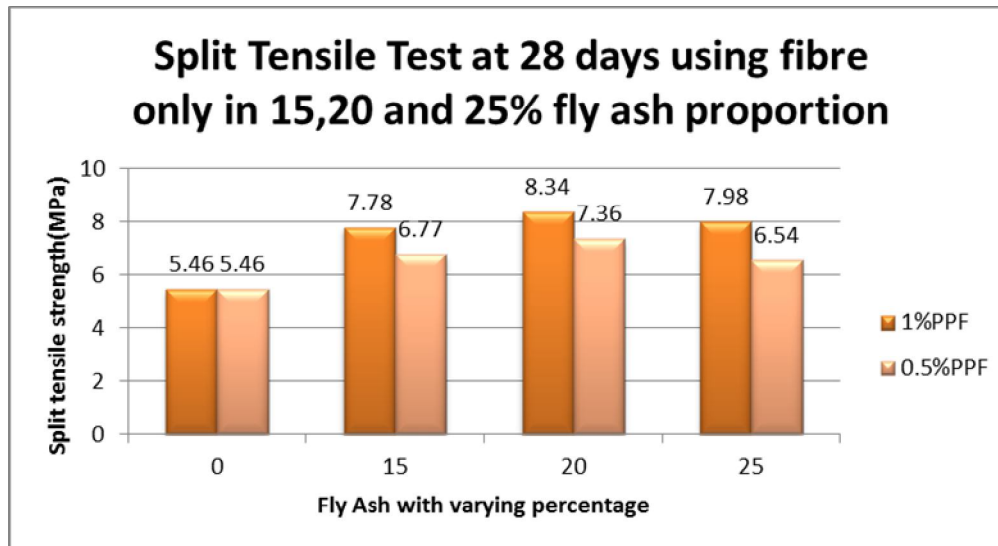


Fig 4.7 showing splitting tensile strength at curing period of 28 days using 1 and 0.5% PPF with varying percentage of fly ash.

From the split tensile strength results given above, the following observations have been done

- The cylindrical strength of plain concrete at 28 days is 6.42 MPa. For 0.50% addition of PPF and with the replacement of cement by 15%, 20% and 25% with fly ash, the percentage improvement comes out to be 5.17, 12.77 and 1.83 respectively. For 1.0% fibre addition and with same fly ash replacement ratio, the percentage improvement is 17.48, 23.02 and 19.55 respectively.
- With the percentage increment of fly ash, split tensile strength decreases but when with the same fly ash content if fibre addition is increased from 0.5% to 1.0%, the strength increases.
- More improvement is seen in case of 20% fly ash with 1% polypropylene fibre while the least is seen in case of 25% fly ash and 0.5% polypropylene fibre.

4.7 Effect of polypropylene fibre on flexural strength

The effect of polypropylene fibres on flexural strength of concrete at 28 days and the graphical representation of results are detailed below in Table 4.8 and fig 4.8 respectively.

Table 4.8: Flexural strength variation in 28 days of FAPPFRC

Type of Mix	Flexural strength, (MPa)	Ratio FC/PC	Percentage Improvement w.r.t PC
Mix 1	7.48	-	-
Mix 8	8.77	1.29	14.70
Mix 9	9.81	2.33	23.75
Mix 10	7.72	0.24	3.10
Mix 11	10.22	2.74	26.81
Mix 12	7.92	0.44	5.55
Mix 13	8.08	0.6	7.43

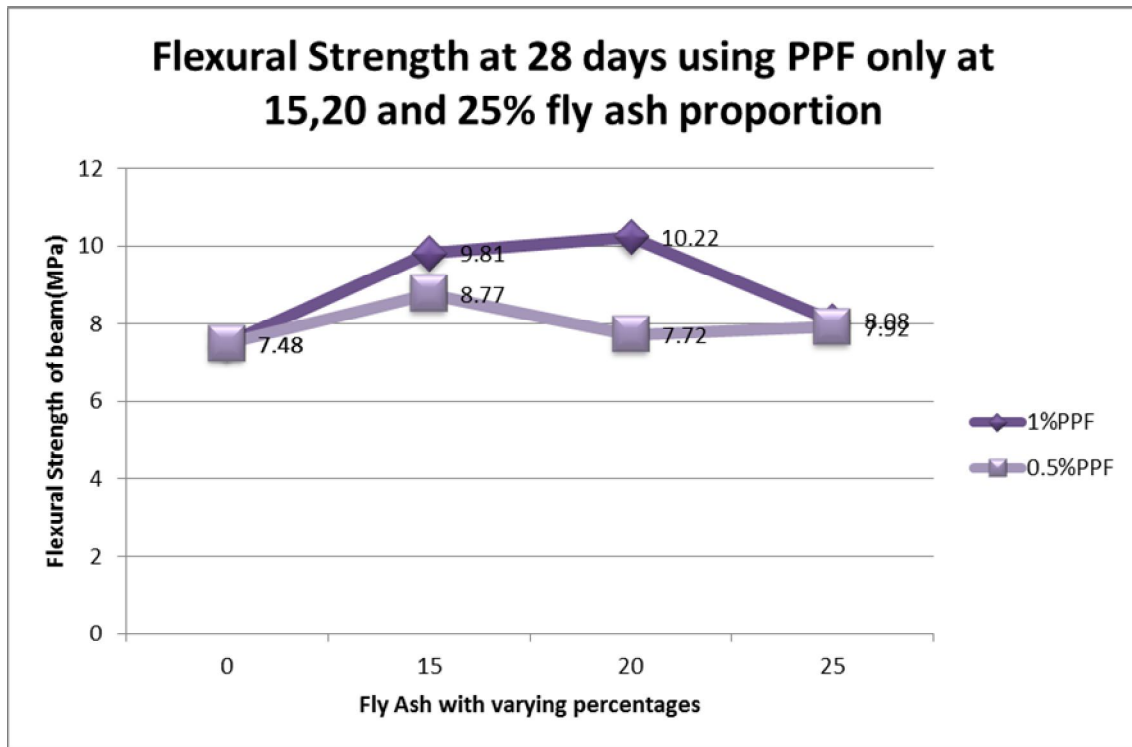


Fig 4.8 Showing flexural strength at curing period of 28 days using 1 and 0.5% PPF at varying percentage of fly ash.

From the above table and graph of flexural strength, following observations have been made.

- The flexural strength of plain concrete is 7.48 MPa. For 0.5% fibre addition and with the replacement of fly ash as 15%, 20% and 25% with the weight of cement, the percentage improvement comes out to be 14.70, 3.10 and 5.55 respectively. For 1.0% fibre addition and with the same replacement of fly ash, the percentage improvement is 23.75, 26.81 and 7.43.
- With the percentage increment of fly ash, split tensile strength decreases but when with the same fly ash content if fibre addition is increased from 0.5% to 1.0%, the strength increases.
- More improvement is seen in case of 20% fly ash with 1% polypropylene fibre while the least is seen in case of 25% fly ash and 0.5% fibre for the same case.

4.8 Closing Remarks

- It is observed that the compressive strength, split tensile strength and flexural strength are improved or enhanced by addition of fibres in fly ash concrete.
- More improvement is observed with SF than PPF.
- Optimum addition of SF content to get the best results is 1%.

5.1 Following conclusions are obtained from the study

- The replacement of cement with flyash by mass in percentage (15, 20 and 25 per cent) decreases the compressive strength, split tensile strength and flexural strength as replacement percentage increases.
- The addition of steel fibres to flyash concrete by volume (0.5 and 1 per cent) increases the compressive strength of flyash concrete at both 7 and 28 days. Similar is the case with split tensile strength of cylinder and flexural strength of beam. Maximum improvement is observed when 15% of FA is replaced with cement and 1% of SF is added to it. While in case of split tensile strength and flexural strength, maximum improvement is seen in case of 20%FA replaced with cement and 1% SF is added to it. But in all the above cases, least improvement is seen in 25%FA replacement along with the addition of 0.5% SF.
- Observing the failure pattern of specimen, it is observed that the addition of steel fibres increases the ductility of flyash concrete.
- Polypropylene fibre addition improves the compressive, split tensile and flexural strength of concrete than plain concrete. But its improvement is less as compared to that of steel fibre for the same case.
- Drastic improvement in strength properties is observed in the case of 15% and 20% fly ash replacement along with addition of fibres while the least improvement is seen in the case of 25% fly ash replacement with fibre addition.
- Water reducing admixture such as superplasticizer is required for workable mix as steel fibre percentage increases.

5.2 Scope of future work

- Durability investigations on fly ash concrete modified with steel as well as polypropylene.
- Only the effect of 0.5% and 1.0% steel and polypropylene fibres were investigated in the study. The percentage replacements can be further varied to study their effect on properties of fly ash concrete.
- Effect of addition of other types of fibres like san fibre, bamboo fibre etc. can be investigated in fly ash concrete.
- Effect of strength and durability of fly ash concrete using different types of steel fibres with variable shapes and aspect ratio can also be investigated.

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