Physical Properties of Steel Fiber Reinforced Cement Composites Made with Fly Ash

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ABSTRACT

The structural behaviour of steel fiber reinforced fly ash concrete under compression and flexure was studied by conducting tests on standard control specimens. The use of steel fibers in fly ash concrete improves its structural properties, especially the flexural tensile strength. Increasing the percentages of fly ash upto 30% and steel fibers upto 1.5% in concrete enhances the flexural tensile strength as well as the compressive strength. Finally, the use of fiber reinforced fly ash concrete is recommended as an alternative to fiber reinforced plain concrete.

KEYWORDS: Steel fibers, Fly ash, Concrete, Flexure, Compression.

INTRODUCTION

The use of pozzolanas in concrete is an old age concept. Pozzolanic materials can be used to replace a part of cement in all construction works. The use of artificial pozzolanas like "Fly ash" as a partial substitute of cement to the extent of (15%-20%) has been accepted as far back as in the year 1930. Fly ash can be successfully used in concrete due to the numerous advantages over ordinary plain concrete, such as increased compressive strength, improved workability, reduced permeability, reduced shrinkage, less bleeding and more economicality... etc. (Fraay, 1990). Though the process of hardening in fly ash concrete is slow at the early stage, the final strength can be comparable to or even higher than that of plain concrete. This improvement can be attributed to better workability and reduction in the voids (Joshi, 1975).

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Fiber Reinforced Fly Ash Concrete

It is well known that concrete is very good in resisting compressive forces, but it is found to be weak against tensile forces. It has the qualities of flexibility and ability to redistribute stresses, but it possesses a low specific modulus, a limited ductility and a very little resistance to cracking. The addition of fly ash to concrete further improves its compressive strength but contributes less to improve its other properties like tensile strength, ductility, resistance to cracking...etc. (Joshi, 1975; Arthanoor, 1976). The potentialities of fly ash concrete can be more exploited by imparting tensile resistance property to it. Investigations carried out by various researchers (Sundara, 1971; Narayanan, 1984) go to prove that the introduction of discrete uniformly dispersed randomly oriented steel fibers to plain concrete not only improves its resistance against tensile forces, but also imparts greater ductility and delays the onset of first flexural crack. In fly ash concrete composites also, the addition of such ash can improve its resistance against tensile stresses, delay the onset of flexural crack and improve ductility (Lal, 1992). Thus, the addition of two materials; namely fibers and fly ash results in a new composite called Fiber Reinforced Fly Ash Concrete, which not only shows better resistance to compressive forces but also exhibits substantial resistance to tensile forces.

Table 1: Properties of the used materials

Material	Property	Value
Cement	1. Specific gravity	3.15
	2. Standard consistency	29%
	3. Initial setting time	58 minutes
	4. Final setting time	255 minutes
	5. Compressive strength at 3 days	170 kg/cm^2
	6. Compressive strength at 7 days	200 kg/cm^2
Fine Aggregate	1. Specific gravity	2.65
	2. Fineness modulus	2.36
	3. Unit weight	1.62 t/m^3
Coarse Aggregate	1. Specific gravity	2.71
	2. Fineness modulus	6.88
	3. Unit weight	1.57 t/m^3
Fly Ash	1. Specific gravity	1.70
	2. Consistency	Non-plastic
	3. Grain size	Fine, Fairly uniform

Mechanism of Fly Ash

Fly ash does not have much cementitious properties by itself, but in the presence of water it reacts with free lime either from cement or from any other source forming higher order hydrated products, which not only enhance strength but also improve durability. With cement, it forms calcium silicate hydrate, calcium mono-sulpho aluminates, calcium tri-sulpho aluminates and calcium hydroxide. These products are highly dense resulting in improved strength and reduced permeability (Arthanoor, 1976).

Role of Fibres

The role of fibers is essential to arrest advancing of crack by applying pinching forces at the crack tips, thus delaying their propagation across the matrix and creating a slow crack propagation stage. The ultimate cracking strain of the composite is thus increased by many times compared to that of unreinforced matrix. The introduction of small, closely spaced, randomly oriented fibers transfers an inherently brittle material with low tensile strength and impact resistance into a strong composite with superior crack resistance, improved ductility and distinctive post cracking behaviour prior to failure (Sundara, 1971; Sridhar, 1971).

PRESENT STUDY

The structural properties of both fiber reinforced concrete as well as fly ash reinforced concrete are well known, and their individual behaviour is also fully understood. In the present study, an effort is made to combine the structural properties of steel fiber reinforcement with those of cement-fly ash concrete. This would make it possible for a designer to combine the advantages of fly ash, like economicality, increased strength, increased workability, reduced voids, ...etc., with those of fiber reinforcement; namely better resistance against cracking and spalling, higher ductility and well-defined post cracking behaviour.

Table 2: Results of ultimate compressive and flexural tensile strengths

Ser. No.	Series	Compressive Load t				Average Comp. Strength kg/cm^2	Flexural Load kg				Average Flexural Strength kg/cm^2	Compressive to Flexural
		P_1	P_2	P_3	$P_{av.}$		P_1	P_2	P_3	$P_{av.}$		
1	F0.0 A00	50.5	45.0	48.5	48.00	213.33	400	370	370	380	30.40	7.02
2	F0.0 A10	51.0	53.0	50.0	51.33	228.13	340	330	350	340	27.20	8.39
3	F0.0 A20	45.5	55.0	56.0	54.00	240.00	350	330	340	330	26.40	9.09
4	F0.0 A30	48.0	47.0	51.5	48.83	217.02	290	240	280	270	21.60	10.05
5	F0.0 A40	45.0	53.5	42.0	43.50	193.33	210	200	210	207	16.56	11.68
6	F0.5 A00	45.5	47.0	46.5	46.33	205.91	420	410	460	430	34.40	6.00
7	F0.5 A10	48.0	49.5	52.5	50.00	222.22	430	410	520	420	33.60	6.61
8	F0.5 A20	56.5	53.0	55.0	54.83	243.69	290	410	400	405	32.40	7.52
9	F0.5 A30	48.0	49.0	48.0	48.33	214.80	370	380	350	367	29.36	7.32
10	F0.5 A40	45.5	45.5	42.5	44.50	197.78	350	350	320	340	27.20	7.27
11	F1.0 A00	43.0	40.0	29.0	41.50	184.44	500	450	480	477	38.16	4.83
12	F1.0 A10	50.5	51.5	46.5	49.50	220.00	430	450	470	450	36.00	6.11
13	F1.0 A20	51.5	52.0	54.0	52.50	233.33	460	410	450	440	35.20	6.63
14	F1.0 A30	49.0	49.0	45.0	47.67	211.87	450	430	420	433	34.64	6.12
15	F1.0 A40	46.0	44.0	46.5	45.50	202.22	390	370	400	387	30.96	6.53
16	F1.5 A00	38.5	39.5	40.0	39.33	174.80	610	640	610	620	49.60	3.53
17	F1.5 A10	44.0	53.5	46.0	45.00	200.00	570	600	490	585	46.80	4.27
18	F1.5 A20	48.0	47.0	44.5	46.50	206.67	470	520	480	490	39.20	5.27
19	F1.5 A30	45.5	42.0	44.0	43.83	194.80	400	390	420	403	32.24	6.04
20	F1.5 A40	36.0	38.0	37.5	37.17	165.20	330	350	330	337	26.96	6.13

EXPERIMENTAL PORGRAMME

The experimental work consisted of tests on standard size control specimens of plain concrete, fly ash concrete and steel fiber reinforced concrete. The tests were conducted to find the compressive strength on cubes of 150mm size and the flexural strength on beams of (500mm x 100mm x 100mm) size with a span of 400 mm under two point loads. The test specimens were divided into four main categories depending upon the percentage of volume of steel fibers ranging from 0.0% to 1.5% in increments of 0.5%, and in each category partial replacement of cement was made by fly ash from 0.0% to 40% in increments of 10%.

Materials Used

Cement: Ordinary Portland cement was procured in one lot for the present study.

Fine Aggregate: Locally available sand was used as fine aggregate. Tests carried out for fineness modulus and specific gravity of sand are tabulated in Table 1.

Coarse Aggregate: Coarse aggregate of maximum nominal size of 20mm was used in the present study. Table 1 shows the properties of the used coarse aggregate.

Steel Fibers: Steel fibers of 0.4mm diameter and 32mm length with an aspect ratio of 80 were used in the present study.

Fly Ash: The various properties determined for the fly ash are given in Table 1.

Table 3: Percentage increase in compressive strength of steel fiber fly ash concrete over plain concrete

		% of Fly ash				
		00	10	20	30	40
% of Steel Fibres	0.0	00	7	13	2	-9
	0.5	-4	4	14	1	-7
	1.0	-14	3	10	-1	-5
	1.5	-18	-6	-3	-9	-23

Mixing and Casting the Specimens

A nominal mix of the proportions (1.0: 1.75: 3.0) (Cement: Fine aggregate: Coarse aggregate) by weight, with a cement content of 300 kg/m^3 and a water-cement ratio of 0.5 was maintained throughout the study. All the required materials for preparing the concrete were weighed as per the required proportions. The cement and fly ash were thoroughly mixed in the dry state, and the sand was added later to the mixture. The mixture was again thoroughly mixed and gently placed over the coarse aggregate. In case of fiber reinforced concrete, fibers were evenly sprinkled during the mixing. Water was finally added to the dry mixture. Plasticizers were used for all mixes taking 0.5% of weight of cement and fly ash to avoid balling effect and to render easy workability. Mixing was carried out until a workable mixture was obtained. The entire mixing was carried out on a dry platform. Concreting was done in the moulds while they were on a platform vibrator. Vibrations were continued for one minute to ensure uniform compaction. The specimens were demoulded after 24 hours of casting and placed in a curing tank for 45 days. The curing period was increased due to the fact that fly ash concrete gains strength slowly and hence instead of 28 day curing, 45 day curing was adopted. After the curing period, the specimens were removed from the curing tank and whitewashed for better visibility of cracks.

Testing of the Specimens

Cubes were tested under a 200 ton compression testing machine. Beams were tested under a universal testing machine of 10 ton capacity for flexure. Deflections at mid-span of the beams were measured with the help of a mechanical dial gauge the least count of which was 0.02mm. Loading was conducted as per the specifications of the relevant codes.

ANALYSIS OF TEST RESULTS

Results obtained from experimental investigations to study the compressive strength as well as the flexural tensile strength of steel fiber fly ash concrete in comparison with plain concrete are presented here for discussion.

Table 4: Percentage increase in compressive strength of steel fiber fly ash concrete over steel fibers concrete

		% of Fly Ash				
		00	10	20	30	40
% of Steel Fibers	0.0	00	7	13	2	-9
	0.5	00	8	18	4	-4
	1.0	00	19	27	15	10
	1.5	00	15	18	12	-6

Table 5: Percentage increase in flexural tensile strength of steel fiber fly ash concrete over plain concrete

		% of Fly Ash				
		00	10	20	30	40
% of Steel Fibers	0.0	00	-11	-13	-29	-46
	0.5	13	11	7	-3	-11
	1.0	26	19	16	14	2
	1.5	63	54	29	6	-11

Table 6: Percentage increase in flexural tensile strength of steel fiber fly ash concrete over fly ash concrete

		% of Fly Ash				
		00	10	20	30	40
% of Steel Fibers	0.0	00	00	00	00	00
	0.5	13	24	23	36	64
	1.0	26	32	33	60	87
	1.5	63	72	49	49	63

Compressive Strength

Cube specimens were tested for compression, and the average ultimate compressive stress was determined from the failure compressive load. The obtained values of average compressive strength are given in Table 2. Curves are plotted as average compressive strength against percentage of volume of steel fibers as well as percentage of volume of fly ash, and are given in Figs. 1 and 2, respectively. Tables 3 and 4 show the percentage increase/decrease in the compressive strength of steel fiber fly ash concrete over the compressive strength of plain concrete as well as the corresponding compressive strength of steel fiber concrete, respectively. From the curves in Figs. 1 and 2, and Table 3, it can be seen that in the specimens without steel fibers, compressive strength increases by 13% with respect to the corresponding value for plain concrete, by using 20% replacement of cement by fly ash. It decreases to 9% for 40% fly ash. A similar trend can be seen in steel fiber fly ash concrete specimens the compressive strength of which increases up to 14% with respect to the corresponding value for plain concrete, by using 0.5%

steel fibers along with 20% replacement of cement by fly ash. The maximum increase in the compressive strength is found in the specimens with 20% fly ash content for all percentages of steel fibers used. The maximum decrease in the compressive strength is found in the specimens with 40% fly ash content with a value of 23% less than the corresponding value for plain concrete with 1.5% of steel fibers as shown in Table 3.

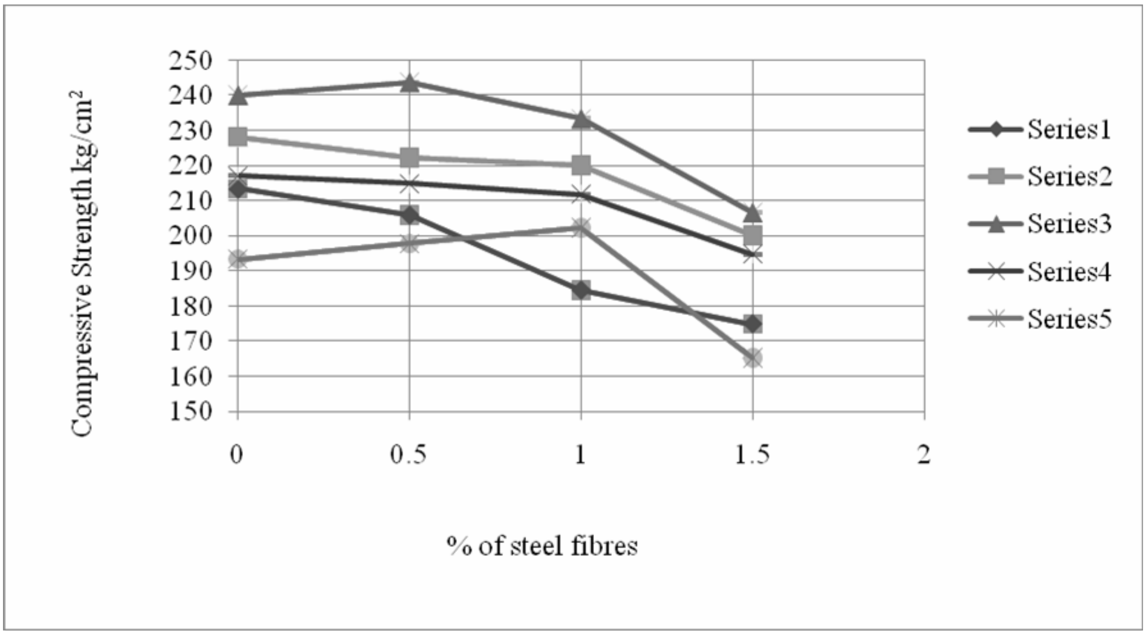

Figure 1: Compressive strength *vs.* percentage of steel fibers

It can also be seen from Fig. 1 that the addition of steel fibers decreases the compressive strength of the specimens without fly ash, whereas this decrease is marginal for specimens with fly ash. From the curves shown in Fig. 2 as well as Table 3, it can be seen that in the specimens without fly ash, compressive strength decreases with the increase of the percentage of steel fibers with a maximum value of 18% with respect to the corresponding value for plain concrete. With respect to the steel fibers' content, the maximum decrease in the compressive strength is found in the specimens with 1.5% steel fibers' content for all percentages of fly ash content, with a maximum value of 23 % less than the corresponding value for plain concrete with 40% of fly ash content. From Fig. 2, it can also be seen that using 15% to 25% replacement of cement by fly ash in concrete increases the compressive strength of the concrete for all percentages of steel fibers used. Compared to the compressive strength values of steel fiber concrete, steel fiber fly ash concrete has higher values of compressive strength ranging from 10% to 27% more than the corresponding values for steel fiber concrete with steel fibers' content of 1.0% to 1.5% for any fly ash content as shown in Table 4.

Flexural Tensile Strength

Flexural test was conducted on beams under two-point loading, and the average ultimate flexural tensile stress was determined from the failure flexural loads. The obtained values of average flexural tensile strength are given in Table 2. Curves are plotted as the average flexural tensile strength against the percentage of volume of steel fibers as well as the percentage of volume of fly ash. Tables 5 and 6 show the percentage of increase/decrease in the flexural tensile strength of steel fiber fly ash concrete over the flexural tensile strength of plain concrete as well as the corresponding flexural tensile strength of fly ash concrete, respectively.

It can be seen from Table 5 that in the beam specimens without steel fibers, the flexural tensile strength decreases with the increase of fly ash content with respect to the corresponding value for plain concrete. The maximum decrease in the flexural tensile strength is found in the specimens with 40% fly ash content with a value of 46% less than the corresponding value for plain concrete and without steel fibers. On the contrary, the addition of steel fibers to the concrete increases the flexural tensile strength of fly ash concrete for all percentages of fly ash content.

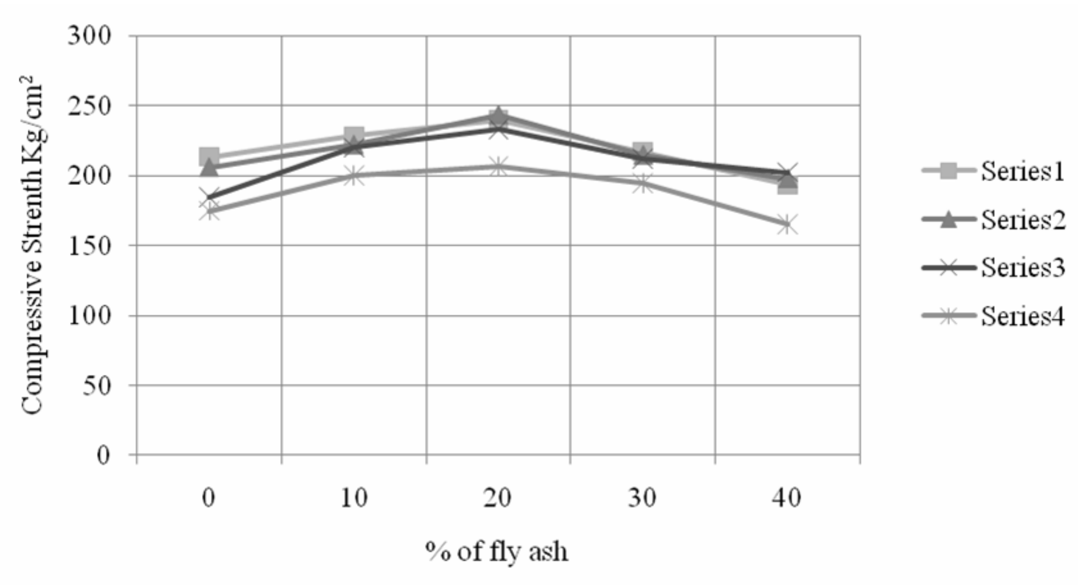

Figure 2: Relationship between compressive strength and fly ash content

The maximum increase in the flexural tensile strength is found in the specimens with 1.5% steel fibers' content with a value of 63% more than the corresponding value for plain concrete with 0.0% fly ash content. It can be noticed that the rates of increase of flexural tensile strength of steel fiber fly ash concrete are lower for all fly ash content percentages with steel fibers' content between 0.5% and 1.0% than the corresponding ones having any other steel fibers' content less than 0.5% and more than 1.0%. It can be seen that for all percentages of steel fibers' content, the flexural tensile strength decreases with the increase of fly ash content with a maximum value of 46% less than the corresponding value for plain concrete. Compared to the flexural tensile strength of fly ash concrete, steel fiber fly ash concrete has higher values of flexural tensile strength ranging from 13% to 87% more than the corresponding ones of fly ash concrete with all steel fibers' contents and all fly ash content percentages as shown in Table 6. The optimum values of steel fibers' content for increasing the flexural tensile strength are between 1.0% and 1.5% for all fly ash content percentages with respect to the corresponding ones of fly ash concrete.

Compressive Strength/ Flexural Strength

The relationship between compressive strength and flexural tensile strength has been recorded in the last column of Table 2. Curves are plotted as the relation between the ratio of compressive strength to flexural tensile strength and the percentage of volume of steel fibers as well as the percentage of volume of fly ash and are given in Figs. 3 and 4, respectively. It can be noticed from Figs. 3 and 4 as well as Table 2 that the ratio of compressive strength to flexural tensile strength decreases with the increase of steel fibers' content for all percentages of fly ash content in the steel fiber fly ash concrete.

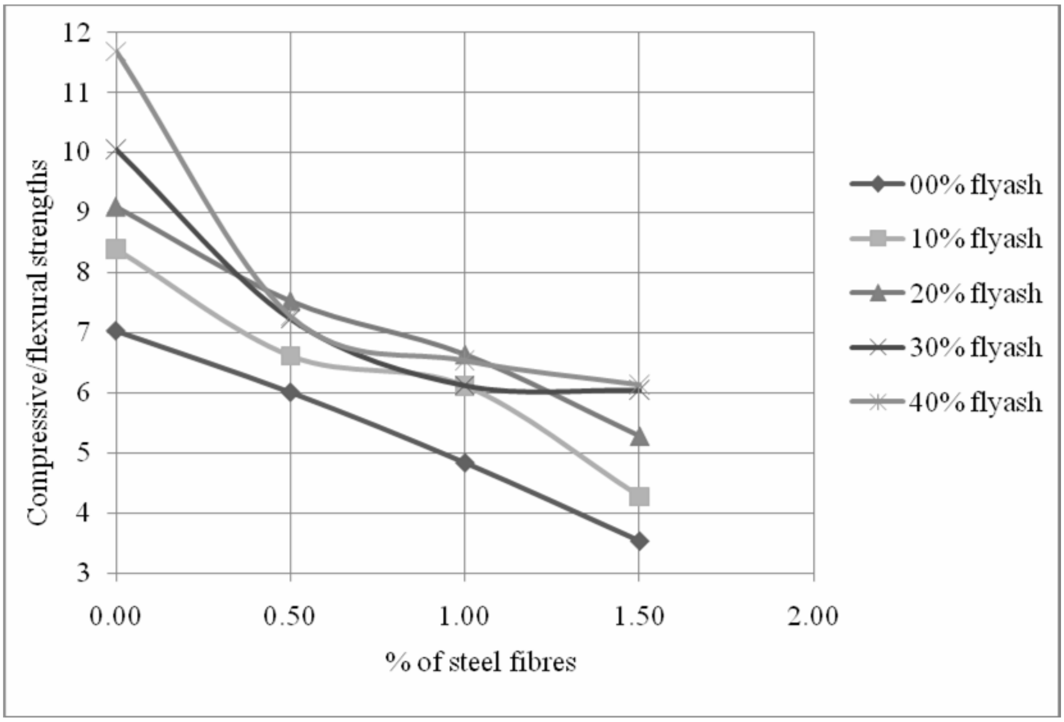

Figure 3: Relation between compressive/flexural strength and steel fibers

The ratio of compressive strength to flexural tensile strength increases with the increase of fly ash content for all percentages of steel fibers' content. Also, it can be seen that at any content of steel fibers, the ratio of compressive strength to flexural tensile strength increases by increasing the fly ash content. On the contrary, the addition of steel fibers to fly ash concrete decreases the ratio of compressive strength to flexural tensile strength for any content of fly ash in the steel fiber fly ash concrete.

The maximum ratio of compressive strength to flexural tensile strength has been noticed at 40% fly ash content without steel fibers with a value of 11.7, whereas the minimum ratio is 3.5 at 1.5% steel fibers' content and without fly ash. This is logical because the compressive strength decreases with the increase of steel fibers' content, while the flexural tensile strength increases with the increase of steel fibers' content as well as the decrease of fly ash content. No significant effect on the ratio of compressive strength to flexural tensile strength has been noticed for fly ash content more than 20% for any steel fibers' content in steel fiber fly ash concrete. This is also true for steel fibers' content more than 1.0 % for any fly ash content.

CONCLUSIONS

From the experimental study conducted on steel fiber fly ash concrete, the following conclusions can be drawn:

1. Steel fiber reinforced concrete is very effective in resisting flexural tensile stresses as compared to compressive stresses.
2. On the contrary, fly ash reinforced concrete is very effective in resisting compressive stresses as compared to flexural tensile stresses.

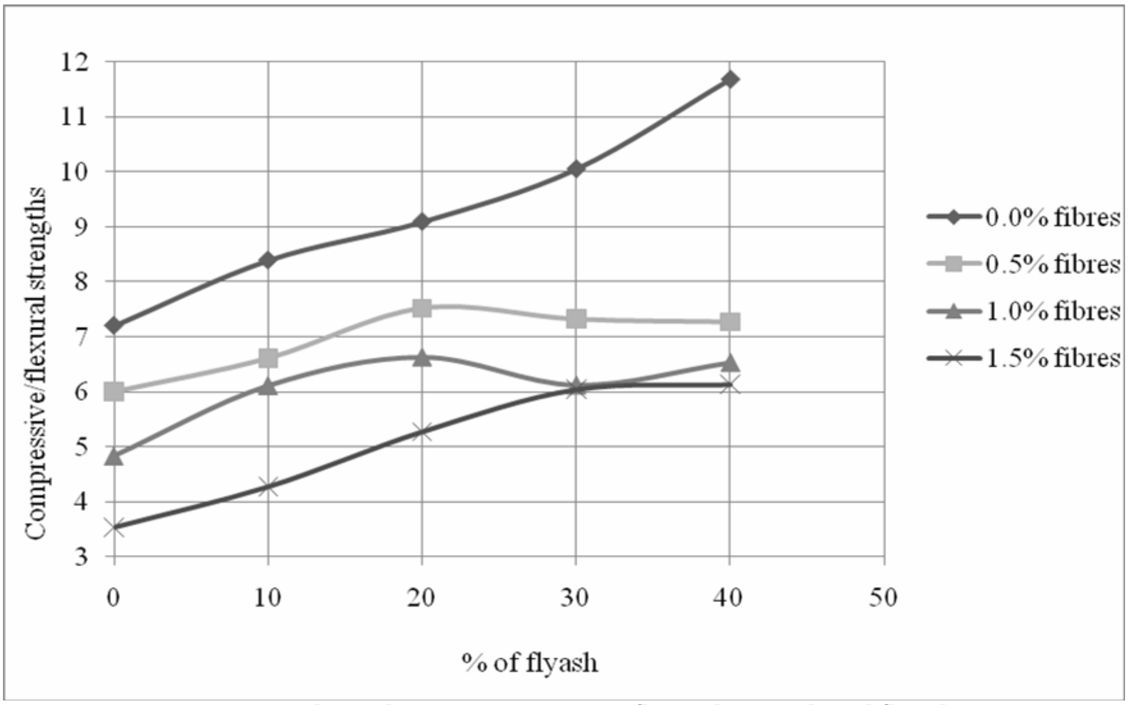

Figure 4: Relation between compressive/flexural strength and fly ash

3. Specimens containing 1.0 % to 1.5% steel fibers with 15% to 25% replacement of cement by fly ash are more effective in resisting flexural tensile stresses as well as compressive stresses. Hence, the optimum percentage of steel fiber fly ash reinforced concrete is around 1.0 % to 1.5% of steel fibers and 15 % to 25% of fly ash.
4. The ratio of compressive strength to flexural tensile strength can be enhanced by the addition of fly ash and the reduction of steel fibers' percentage.
5. The workability of concrete will also get enhanced by the addition of fly ash, which is required especially in higher percentages of steel fibers.
6. The addition of different percentages of steel fibers to fly ash concrete will enhance the flexural tensile stresses up to 87%, but will reduce the compressive stresses to 23 %.
7. Also, the addition of fly ash in different replacement percentages of cement to steel fiber concrete will enhance the compressive stresses up to 27% but will reduce the flexural tensile stresses to 46%.
8. The ductility of concrete will get enhanced by the addition of steel fibers as well as fly ash.

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