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Flexural behaviour of reinforced concrete beams using high volume fly ash concrete confinement in compression zone

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Abstract

In India, the total production of fly ash is nearly as much as production of cement. But utilization of fly ash is only about 5% of the population in India. In the recent days, the importance and use of fly ash in concrete has grown so much that it has almost become a common ingredient in concrete. This project deals with flexural behaviour of reinforced concrete beam using high volume fly ash concrete confinement in compression zone. To study fly ash mixed concrete, the various mix designs are prepared for various proportions of Fly Ash in proportions of cement such as 0%, 50%, 55%, and 60% for M40 grade of concrete. Based on the results, 50 percent replacement of fly ash with cement and addition of 1.5 percent super plasticizer gave better compressive strength and the result is taken for analysis of Flexural behaviour of R.C.C beams using High Volume Fly Ash concrete confinement in compression zone. The experiments show that strength of R.C.C beam using high volume fly ash concrete is less at earlier stages and it gains more strength at later stage than the conventional concrete.

Keywords: Fly ash, super plasticizer, confinement in compression zone

1. Introduction

Fly ash is a finely divided residue resulting from the combustion of powered coal and transported by the flue gases and collected by electrostatic precipitator. Extensive research has been done all over the world on the benefits that could be accrued in the utilization of fly ash as a supplementary cementitious material. The use of fly ash concrete admixture not only extends technical advantages to the properties of concrete but also contributes to the environmental pollution control

The High-Volume Flyash Concrete (HVFAC) offers a holistic solution to the problem of meeting the increasing demands for concrete in the future in a sustainable manner and at a reduced or no additional cost, and the same time reducing the environmental impacts of cement industry and coal-fired power industry (8). HVFAC has lower early compressive strength but very good later age strength which continues to increase over several months. HVFAC has also performed better in terms of its elastic modulus, flexural, tensile and abrasion strengths. The permeability and hence the durability characterics of HVFAC are far more superior than plain concrete (15). Fly Ash in concrete reduces compressive strength at early ages but there is a drastic increase in the compressive strength at later ages. The early strength is reduced further it the percentage at replacement is increased. But, on the other hand when the percentage of replacement is increased the water/binder ratio gets reduced, thereby, increasing the later age compressive strength. Also, It is observed that the later age strength of concretes having more than 40% replacement of cement by fly ash suffers adversely though water/binder ratio is gradually reduced. For concretes with less than 40% replacement of cement, the characteristic strength at 28 days is on higher side. Whereas, for concrete with 40% replacement of cement, the 28 days compressive strength is at par with that of plain concrete. The reason may be due to water/binder ratio, quality of cement and the age of curing are inter-related and effect of high strength concrete (18). The addition of fly ash to OPC in concrete improves the properties of fresh concrete and enhance parameters of which indicate durability. Fly ash should be added only in the batching plant, where good control on quantity and quality can be ensured (1).

Based on the above literatures studied, partial replacement of fly ash with cement is made for the preparation of concrete and flexural behaviour of high volume fly ash concrete beams are studied and the results compared with the conventional concrete.

2. Materials

Ordinary Portland cement (OPC) is the most important type of cement. OPC is divided into 33, 43 and 53 grades as per IS 269:1989,IS 8112:1989 and IS 12269:1987 depending upon the strength of the concrete at 28 days. For this project, Priya cement (OPC 43 grade) is used. The strength of concrete depends on coarse aggregate. These should be hard, strong, dense, durable, rough and free from salt, alkali and organic matters. Blue organic, gneiss, crystalline lime stone or good sand stone are crushed in to small pieces of varying from sizes 5mm to 20mm. Fine aggregates size will be between 150 microns to 4.75mm. A well graded siliceous quartz sand which contains grains of almost all sizes in equal proportions is best suited for concrete works. Angular grained sand is preferable to round grained sand since it provides good interlocking properties. Water used for mixing and curing of concrete shall be clean and free injurious amounts of oils, acids, alkalis, salts, sugar, organic material or other substances that may be deleterious to concrete or steel. Potable water is generally considered satisfactory for mixing concrete. PH value shall not be less than 6 will be preferred.

Fly ash is a by-product from coal fired electricity generating power plants. Fly ash is collected in electrostatic precipitators or bag houses. Fly ash can be used in concrete as a partial replacement for Ordinary Portland Cement (OPC). The main aspects of the concrete performance that will be improved by the use of fly ash are increased long-term strength and reduced permeability of the concrete, resulting in potentially better durability of concrete. The use of fly ash in concrete can also address some specific durability issues such as sulphate attack and alkali silica reaction. Fly ash particles are generally spherical in shape. Fly ash for this project is received from Mettur Themal Power Plants, Tamil Nadu.

The material to be used as reinforcement in concrete should have a high tensile strength, high modulus of elasticity and almost the same coefficient of linear expansion as that of concrete. For seismic regions High Yield Deformed bars of grade Fe 415 steel is generally preferred and the same type of steel is used for this project. Superplasticizers are modern type of water reducing admixtures, basically a chemical or mixture of chemicals that imparts higher workability to concrete. Here CONFLAST SP 430 in liquid form is used in concrete as super plasticizers. TEC mix 100 is integral water proofer liquid for all types of concrete. These improve workability and reduce permeability of concrete. These are added to concrete in the ratio of 250 gm/50 Kg of cement.

3. Test

3.1 Tests on fine and coarse aggregate

The various properties like fineness modulus, specific gravity, bulk density and percentage of void ratio are examined both on fine and coarse aggregate to check the property of fine and coarse aggregate conforming to IS:2386 (PART-III):1963.

Table 1
Properties of Fine Aggregate

Aggregate	Property	Result
Fine aggregate	Fineness modulus	3.30
	Specific gravity	2.49
	Bulk density	1.75 gm/cc
	Percentage of Voids	29.72

Table 2
Properties of coarse aggregate

Aggregate	Property	Result
Fine aggregate	Fineness modulus	4.34
	Specific gravity	2.78

Table 3
Properties of cement selected for the test

material	Property	Result
Cement	Fineness of cement	4.00%
	Initial setting time	40 min.
	Final setting time	410 min.

3.2 Test on cement

For identifing the best cement, the following properties of cement is tested, In general, the fineness, that is, the residue by weight on 90 micron IS seive shall not be greater than 10%, the soundness expansion in Le chatelier apparatus shall not be greater than 10mm; the initial setting time shall not be less than 30 minutes: the final setting time shall not be greater than 10 hours. The insoluble residue in ordinary cements shall not be more than 15%.

3.3 Test on Plain cement Concrete

Compression test is the most common test conducted on hardened concrete. For this generally concrete cubes of size 15x15x15cm confirming to IS 10086:1992. The cured concrete cubes are tested in a compression testing machine for 7 and 28 days of curing at room temperature.

3.4 Test on Reinforced cement concrete beams

Concrete as we know is relatively strong in compression and weak in tension. Here in this project, tensile strength is being considered. Steel rods are provided in beams to resist all tensile forces. However , tensile stresses are like to develop in concrete due to drying shrinkage, rusting of steel reinforcement, temperature gradient etc., Therefore, this knowledge is useful in the design of pavement slabs and airfield runways as flexural tension is critical in these areas. For this test, 2 Nos of 12mm dia rods are taken as main reinforcement and 2 Nos of 12mm dia rods as hanger rods. 8mm dia rods are used as stirrups. As per I.S.456-2000 code, the maximum spacing of stirrups is 0.7d (d = Effective depth of beam). Here stirrups are arranged in such a manner of spacing of 0.375d and 0.75d for full effective depth and half the effective depth to the required beams. Proper cover around the steel guage arrangement was made including oiling the sides of the mould surfaces before concreting.

4. Casting and compacting

Beams were casted as per the above specifications for conventional concrete and high volume fly ash concrete. The compacting was carried out by hand without disturbing the steel gauge arrangements. The size of the finished surface of beam were maintained to 15cm x 15cm x 70cm. Care was taken to avoid segregation of aggregates and laitance. The test specimens were removed from moulds carefully and stored in water tank for curing. The specimens were not allowed to dry at any time until they had been tested.

5. Method of testing on RC Beam specimens

The cured concrete beams were tested after 7 and 28 days of curing at room temperature. Direct measurements for tensile strength are difficult. Beam tests are found to be dependable to measure flexural strength property of concrete. Loads were applied by two point load method. Loads were applied carefully on rollers which were placed above the specimens at 20cm apart. The load will be divided equally between the two loading rollers with axial in nature.

In case of symmetrical loading, the critical crack may appear at any section, which is not strong enough to resist the stress and lies within the middle third of span where the bending moment is maximum. The load was increased until the specimen fails, the maximum load applied to the specimen during the test was recorded and it was noted that the cracks formed from the top.

The flexural strength of the specimen is expressed as modulus of rupture (f_b).

$$f_b = (3p \times a) / b \times d^2 \tag{1}$$

where f_b in MPa.

where a = Distance between line of fracture and the nearer support measured on the centre line of the tensile of the specimen.

b = Measured width of specimen (in cm)
d = Measured depth of specimen (in cm) at point of failure
l = Length of span which the specimen was supported (in cm)
p = Maximum load applied to the specimen (in kg)

The value of modulus of rupture (extreme fibre stress in bending) depends on the dimension of the beam and manner of loading. concrete cubes were casted for a size of 15cm x 15cm x15cm for both conventional concrete and high volume fly ash concrete. Compressive strength between them was analysed.

The following Table 4 and Figure 1 represent the compressive strength for the conventional concrete of no fly ash and no admixture.

Table 4
Compressive Strength for conventional Concrete

Cube Mark	Curing period	Ultimate load (KN)	Comp. stgth(N/mm^2)
A	7 days	74.50	32.48
A	7 days	75.50	32.92
A	7 days	77.00	33.57
A	28 days	130.00	56.68
A	28 days	126.50	55.15
A	28 days	125.00	54.50

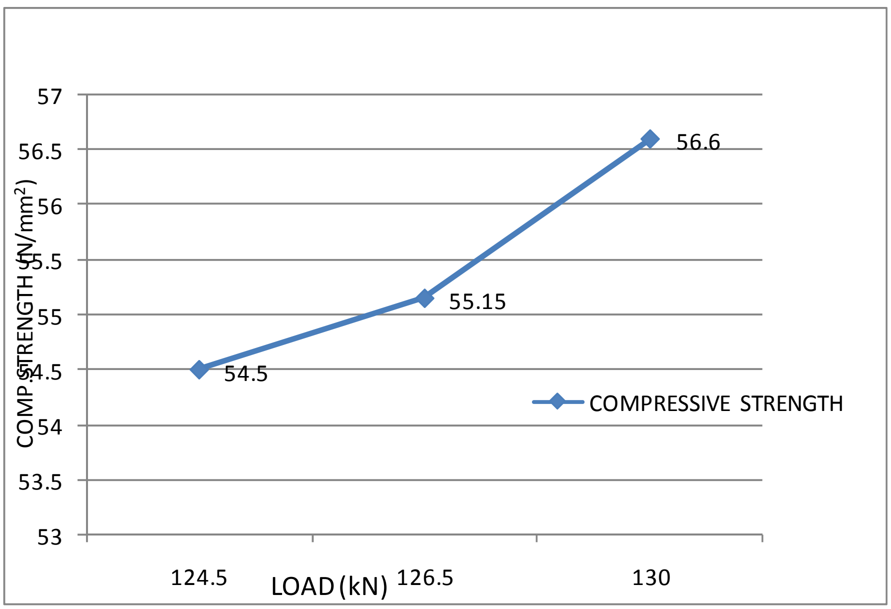

Fig. 1. Compressive strength – 28 days curing (Conventional Concrete)

It has been noted that for 7 days cured specimens having compressive strength of around $33N/mm^2$. It is nearly 69% of target strength. For the same proportions in 28 days of curing the compressive strength was above the target strength. This show concrete attains strength over proper curing and age.

It has been noted that for three cubes of same mix proportions having the compressive strength values of around 55.50 N/mm^2 which is above the target strength of 48.25 N/mm^2.

The following Table 5 & Figure 2 represents the compressive strength for the concrete with replacement of cement with 50% fly ash and 1.5% super plasticizer.

Table 5
Compressive Strength for High Volume Fly Ash Concrete

Cube Mark	Curing period	Ultimate load (kN)	Comp. strength (N/mm^2)
B	7 days	72.50	31.61
B	7 days	71.50	31.17
B	7 days	73.00	31.83
B	28 days	109.00	47.52
B	28 days	109.00	47.52
B	28 days	111.50	48.61

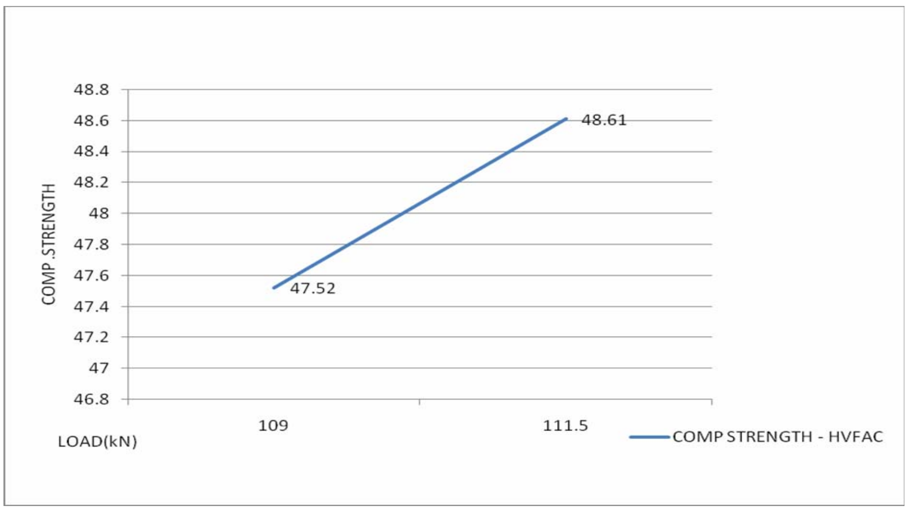

Fig. 2. Compressive strength – 28 days curing (HVFAC)

It has been noted that for 7 days cured specimens having compressive strength of around 31.50N/mm^2. It is nearly 65% of target strength. For the same proportions in 28 days of curing the compressive strength was nearly to the target strength. This show high volume fly ash concrete attains strength over proper curing and age. Fly ash concrete will gains strength at later stages than ordinary concrete.

It has been noted that for three cubes of same mix proportions having the compressive strength values of around 48 N/mm^2 which is nearly the target strength of 48.25 N/mm^2. However, our design mix is 40 N/mm^2. Hence, the mix proportion of 50% replacement of cement with fly ash (including 1.5% super plastizers) is taken for designing.

6. Tests on reinforced concrete beams

For testing flexural behavior of beams, using conventional concrete and high volume fly ash concrete, beams were casted and tests were conducted over beams in Universal Testing Machine. Firstly, beams were casted with traditional conventional concrete with proper arrangement of steel gauge arrangements. The following Table No: 6 represents the flexural behaviour for the conventional concrete of no fly ash and no admixture with spacing of stirrups 0.75d (d= Effective depth).

Table 6
Flexural Behaviour for conventional Concrete (0.75d)

No of days	Depth of stirrup	Load at failure (kg)	Distance (in cm)			Modulus of rupture (fb) MPa
			a	b	d	
7	Full depth	4600.00	19.0	15.0	13.0	103.44
7	Half depth	4300.00	17.2	15.0	12.2	99.38
28	Full depth	6600.00	19.5	15.0	12.5	164.74
28	Half depth	6200.00	18.0	15.0	12.1	152.45

It has been noted that the modulus of rupture is 103.44 MPa and 164.74 Mpa to spacing of stirrups having full depth for 7 days and 28 days respectively. This denotes the increase in modulus of rupture value at later stages. Similarly the modulus of rupture is 99.38 MPa and 152.45 Mpa to spacing of stirrups having half depth for 7 days and 28 days respectively. This denotes the increase in modulus of rupture value at later stages. Modulus of rupture value decreased to half depth stirrups because alternate stirrups only having full shape.

The following Table 7 represents the flexural behaviour for the conventional concrete of no fly ash and no admixture with spacing of stirrups 0.375d (d= Effective depth).

Table 7
Flexural Behaviour for conventional Concrete (0.375d)

No of days	Depth of stirrup	Load at failure (kg)	Distance (in cm)			Modulus of rupture (f_b)
			a	b	d	
7	Full depth	4900.00	18.5	15.0	13.2	104.05
7	Half depth	4600.00	17.4	15.0	12.6	100.83
28	Full depth	7000.00	19.7	15.0	12.2	185.30
28	Half depth	6500.00	19.0	15.0	12.1	168.70

It has been noted that the modulus of rupture is 104.05 MPa and 185.30 Mpa to spacing of stirrups having full depth for 7 days and 28 days respectively. This denotes the increase in modulus of rupture value at later stages. Similarly the modulus of rupture is 100.83 MPa and 168.70 Mpa to spacing of stirrups having half depth for 7 days and 28 days respectively. This denotes the increase in modulus of rupture value at later stages. Modulus of rupture value decreased to half depth stirrups because alternate stirrups only having full shape. By comparing the spacing's of 0.75d with 0.375d, it is noted that the reduction in spacing will increase in modulus of rupture. However it may lead to segregation of aggregates. The following table No: 8 represents the flexural behaviour for the high volume fly concrete (replacement of 50% fly ash with 1.5% super plasticizer) at placing of stirrups 0.75d (d= Effective depth).

Table 8
Flexural Behaviour for High volume fly ash Concrete (0.75d)

No of days	Depth of stirrup	Load at failure (kg)	Distance (in cm)			Modulus of rupture (f_b)
			a	b	d	
7	Full depth	4000.00	18.4	15.0	12.7	91.26
7	Half depth	3700.00	18.4	15.0	12.5	88.56
28	Full depth	4500.00	19.1	15.0	12.7	106.58
28	Half depth	4200.00	18.9	15.0	12.6	100.00

It has been noted that the modulus of rupture is 91.26 MPa and 106.58 Mpa to spacing of stirrups having full depth for 7 days and 28 days respectively. This denotes the increase in modulus of rupture value at later stages. Similarly the modulus of rupture is 88.56 MPa and 100.00 Mpa to spacing of stirrups having half depth for 7 days and 28 days respectively. This denotes the increase in modulus of rupture value at later stages. Modulus of rupture value decreased to half depth stirrups because alternate stirrups only having full shape. It is noted that compared to strength of conventional concrete the values of modulus of rupture are decreasing due to replacement of cement.

The following Table 9 represents the flexural behaviour for the high volume fly concrete (replacement of 50% fly ash with 1.5% super plasticizer) at placing of stirrups 0.375d (d= Effective depth).

Table 9
Flexural Behaviour for High volume fly ash Concrete (0.375d)

No of days	Depth of stirrup	Load at failure (kg)	Distance (in cm)			Modulus of rupture (f_b)
			a	b	d	
7	Full depth	4400.00	17.8	15.0	12.8	95.60
7	Half depth	4200.00	17.2	15.0	12.4	93.96
28	Full depth	5600.00	18.6	15.0	12.7	129.16
28	Half depth	5100.00	18.8	15.0	12.4	124.72

It has been noted that the modulus of rupture is 95.60 MPa and 129.16 Mpa to spacing of stirrups having full depth for 7 days and 28 days respectively. This denotes the increase in modulus of rupture value at later stages. Similarly the modulus of rupture is 93.96 MPa and 124.72 Mpa to spacing of stirrups having half depth for 7 days and 28 days respectively. This denotes the increase in modulus of rupture value at later stages. Modulus of rupture value decreased to half depth stirrups because alternate stirrups only having full shape.

It is noted that compared to strength of conventional concrete the values of modulus of rupture are decreasing due to replacement of cement. By comparing the spacing's of 0.75d with 0.375d, it is noted that the reduction in spacing will increase in modulus of rupture. However it may lead to segregation of aggregates.

It is found that for both 0.75d and 0.375d spacing of full depth stirrups, the flexural strength for high volume fly ash concrete is lower than the conventional concrete. Similarly, the half depth of stirrups also shows reduction in flexural strength in high volume fly ash concrete. This is due to alternate half depth stirrups.

It is found that for both 0.75d and 0.375d spacing of full depth stirrups, the flexural strength for high volume fly ash concrete is lower than the conventional concrete. Similarly, for half depth stirrups also there is reduction in flexural strength in high volume fly ash concrete. This is due to alternate half depth stirrups. But for 28 days curing, the flexural strength is increased to certain extent than 7 days strength. It is noted that the high volume fly ash concrete will gain strength at later stages. It is found that the flexural strength of concrete for 0.75d and 0.375d spacing of half depth stirrups to 7 and 28 days curing period is more than the high volume fly ash concrete. This is due to 50% replacement of cement with fly ash. However, the flexural strength of beams in high volume fly ash concrete may be increased at later stages. It is found that the value of flexural strength to half depth stirrups is lower than full depth stirrups spacing. This is due to alternate half depth stirrups spacing.

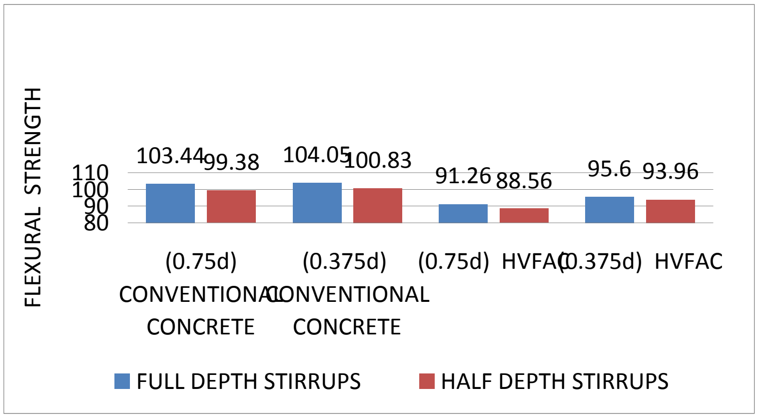

Fig. 3. Flexural Strength for 7 days curing for beams

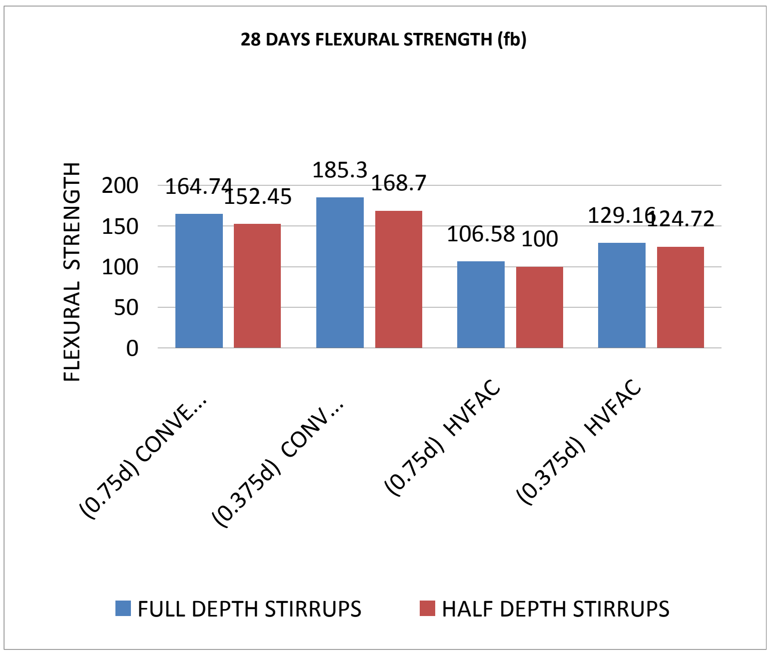

Fig. 4. Flexural Strength for 28 days curing for beams

7. Discussion and conclusions

Hence for analysing the flexural behaviour of conventional concrete and high volume Fly ash Concrete for various percentage of replacement fly ash with cement, the modulus of rupture is calculated and results were compared. On comparison it was noted that for both conventional and high volume fly ash concrete, 0.375d spacing of stirrups gives better result for confinements and regarding economy about 50 % savings in cement and 13% in steel is saved. By modifying fly ash - cement ratio, with suitable super plasticizers different healthy results may be achieved and that will be helpful in concrete industry and solution for recycling of fly ash in future.

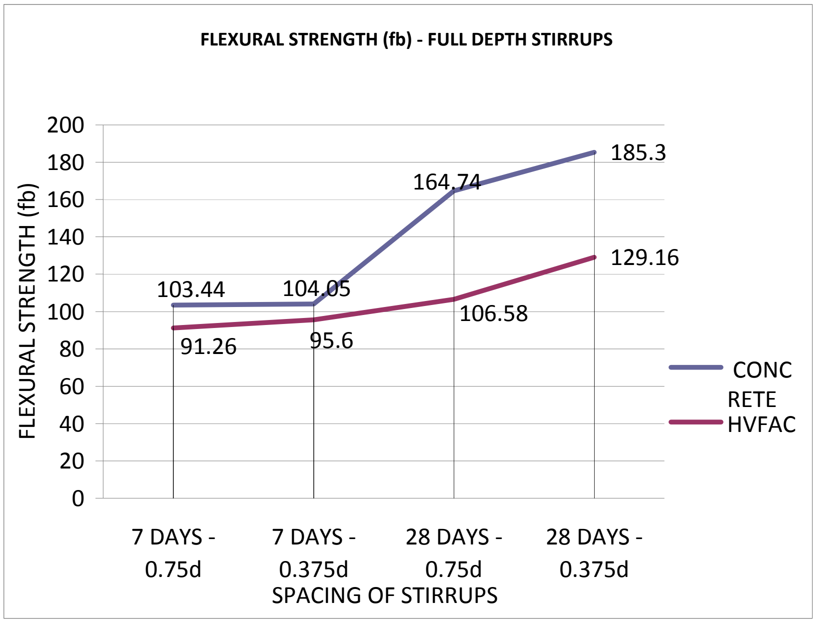

Fig. 5. Flexural strength (fb) for full depth stirrups

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