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Optimizing the Use of Compression Zone Concrete in Hybrid Concrete Beams

Abhijith P. Anil & V. Jayadevan

Abstract — A beam is a horizontal flexural member which provides support to the slab and walls in a structure. In a normal beam, above neutral axis (NA), concrete takes compressive stress and below NA, steel takes tensile stress. Concrete below NA is known as sacrificial concrete which acts only as a medium to transfer strain to steel. This is the basis for the concept of hybrid concrete (HC) beams. This study is concerned with a new type of composite beam where two grades of concretes are used. This study is focused on casting and testing of normal and HC beams. One type of HC beam is fabricated using high strength concrete above neutral axis and high volume fly ash concrete (HVFC) below the neutral axis. Second one is made with high strength concrete only on middle third portion above NA and the entire remaining portions with high volume fly ash concrete (HVFC).
Index Terms—: High Strength Concrete, High-volume Fly Ash Concrete, Hybrid Concrete beam

1 INTRODUCTION

Modern world is always trying to find new, better and economical materials to manufacture new products, which are beneficial and economical to the industry. Today, a significant growth is observed in the manufacture of composite material. According to theory of flexure, for initially straight beams, plane sections remain plane and perpendicular to the longitudinal axis even after bending and in deformed sections, planes of this cross-section have a common intersection i.e. any time originally parallel to the longitudinal axis of the beam becomes an arc of a circle. We know that when a beam is under bending, the fibers at the bottom will be tensioned (Elongate) while fibers at the top will be compressed (shortened). There are some fibers which remain unaffected in length as they are not strained, that is, they do not carry any stress. The plane containing such fibers is called as neutral surface. The line of intersection between the neutral surface and the transverse exploratory section is called as the neutral axis (N.A.). Concrete is weak in tension, to take this tension steel reinforcement is provided at the tension zone of the beam section. Compressive stresses are induced above the neutral axis; so compressive strength of the concrete lying above neutral axis is very important parameter. Because of this a compressive force induces in the top zone at a distance of 0.42 X_u (X_u is the neutral axis distance from top of section). The tension force acts at centroid of steel reinforcement provided at tension zone of the section. The distance between the point of action of compressive force and tension force is called as lever arm distance.

• *Abhijith P. Anil, currently pursing master's degree in Structural Engineering, Vidya Academy of Science and Technology, Thrissur, Kerala, PH-9048882601 E-mail: abhijithpalukkasseri@gmail.com*

• V. Jayadevan, *Visiting Professor, CE Dept., Vidya Academy of Science And Technology, Thrissur, E-mail: vjdcricket@gmail.com*

Lever arm distance is directly proportional to moment of resistance. So, logically there is no need of any concrete on tension side. But this concrete is provided on tension side acts as strain transferring media to steel and is called as 'sacrificial concrete'. A lot of researches conducted to reduce size of the beam and removal of sacrificial concrete and make the structures economical. But comparatively less researches and studies made till now on replacement of sacrificial concrete in case of deep beams. In designing of structures, economy is also a major factor. When considering economy and safety of the structures, it leads to the concepts of "Hybrid Concrete (HC) Beams". A hybrid concrete beam is similar to a normal beam but it is cast with two different grades concrete above and below the neutral axis. HC beam is an effective application of engineering in building construction works to achieve economy and environmental friendliness.

Usage of High Volumes of Fly Ash in concrete is gaining significance and it is considered as a sustainable and economic option for many concrete constructions. The experimental results show that, HVFAC has low initial strength but later age HVFAC shows continuous increase in strength properties. Significantly, both the crack width and drying shrinkage reduces and thus contribute to the long term durability of concrete. HVFA Concrete exhibits comparable costs, increased strengths after 56 days and enhanced durability. Thus, the HVFA concrete is more suitable for warm weather and where early stage strength is not critical. Concrete containing more than 50% of fly ash content by mass of the total cementitious materials is termed as High Volume Fly ash Concrete (HVFAC). While concrete with fly ash content of upto 25% is routinely used, high volumes of fly ash content are not common due to lower early age strengths. However, of late, researchers observed that replacement of cement by fly ash can go up to 50% with a wide range of benefits. However, the strength development is slower in HVFA concrete when compared to PCC but the pozzolanic properties of fly ash result in long term strengths comparable to or better than the conventional concrete. Thus, though it may seem that the HVFA mixture would have lower strengths at early stages due to decreased cement content, low water cement ratio and high admixture content overcome the adverse effects. Application of fly ash in concrete will enable concrete to be more sustainable.

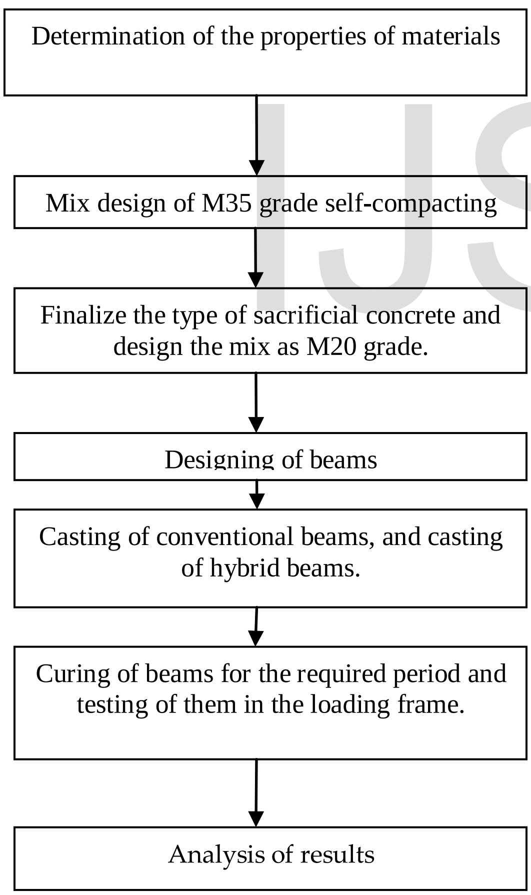
1.2 Overview of the project:

This study is concerned with replacement of sacrificial concrete in the tension zone of RCC beam to improve in terms of constructability and material optimization. This study is focused on fabrication of the Hybrid Concrete (HC) beam. A normal reinforced concrete (RC) beam and HC beam (Rectangular) are fabricated and tested. HC beam comprises of high strength concrete (self-compacting concrete) on most stressed region (middle third above NA) and sacrificial concrete on rest. For sacrificial concrete, high volume fly ash concrete is used.

1.3 Objectives

The main objective of proposed work is to minimize the consumption of cement substantially and thus decrease the emission of CO2 into the environment by this reduction of cement and to reduce the load to the column and foundation and thereby reduce the self-weight of beams. There by minimize the construction cost.

2 Methodology



3 Materials

3.1 Self compacting concrete

The high strength concrete on compression zone is self-compacting concrete. Self-compacting concrete or simply SCC is also called as self-leveling concrete, self-consolidating concrete or vibration free concrete. SCC is highly flowable, non-segregating and cohesive concrete which can spread and fill the formwork with reinforcement by means of its self-weight. High deformability, low yield stress, moderate viscosities are the important parameters of self-compacting concrete, which ensure the uniform suspension of solid particles during the process of manufacturing of concrete. Self-compacting concrete are generally used for casting complicated or heavily reinforced sections, raft foundations, retaining walls, pile foundations, repair, restoring and for renewal works. In this study SCC is used as HSC in compression zone. Super plastizicers and Viscosity Modifying Agent (VMA) is used to achieve SCC.

3.2 Material properties

Properties of material used in this study were obtained either by testing of the corresponding material or by referring the user's manual provided by the Manufacturer.

TABLE 1
PROPERTIES OF CEMENT

Specific gravity	3.15
Consistency	29%
Consistency	29%
Initial setting time	80 minutes
Final setting time	360 minutes

TABLE 2
PROPERTIES OF FINE AGGREGATE

PROPERTIESOF FINE AGGREATE	
Specific gravity	2.51
Water absorption	1.9%
Fineness modulus	5.02
Bulk density(Loose)	1.272 g/cc
Bulk density(compact)	1.594 g/cc
Grading zone	II

TABLE 3
PROPERTIES OF COARSE AGGREGATE

PROPERTIES OF COARSE AGREGATE	
Specific gravity	2.7
Water absorption	0.29%
Bulk density(Loose)	1.58 g/cc
Bulk density(compact)	1.61 g/cc

TABLE 4
PROPERTIES OF FLYASH

PROPERTIES OF FLYASH	
Specific gravity	2.7
Fineness	0.29%

TABLE 5
PROPERTIES OF SUPERPASTIZICER AND VMA

SPECIFIC GRAVITY OF SUPERPASTIZICER AND VMA	
Super plasticizer	1.3
VMA	1.2

4 MIX DESIGN

For fixing sacrificial concrete specimens of HVFAC with fly ash percentages 50,60,70,80 made. The HSC in compression zone is made as SCC due to member level study deals with Hybrid Beams of two grade of concrete. The mix design proportion of HSC and HVFAC are given in table 6

TABLE 6
MIX DESIGN DETAILS

Type of concrete	Mix proportion (WATER : CEMENT : FA: CA: SUPERPLASTIZICR)
HSC	0.429:1:1.37:1.50:0.015
HVFAC 50%	0.41:1:1.07:1.98:0
HVFAC 60%	0.41:1:1.06:1.95:0
HVFAC 70%	0.41:1:1.05:1.93:0
HVFAC 80%	0.41:1:1.03:1.90:0

4 TESTS FOR STRENGTH REQUIREMENTS OF HVFAC AND HSC

The strength requirements are important than the workability requirements, to select a concrete mix. Only the concrete mix with adequate strength can use in the fabrication of structural members. Hence the primary consideration of each mix design is target strength. Generally three types of laboratory tests are performed to understand the strength requirements of concrete mix and they are split tensile test, Compressive strength test and flexural strength test. The compressive strength test and split tensile strength test are performed in this study.

4.1 Compressive strength of HVFAC AND HSC

Compressive strength test is a commonly used laboratory test, to determine the strength of concrete under compressive loads. This test can be done either by Compression testing machine (CTM) or by Universal testing machine (UTM). In this test, standard sized (150mmX150mmX150mm) cubes were subjected to gradually increasing compressive load until failure of specimen.The test results given below Table 7

TABLE 7: COMPRESSION TEST RESULTS

Mix	Avg. Compressive strength in N/mm²		
	7th Day	28th Day	56th Day
HSC	34.44	46.04	54
HVFAC 50%	19.55	31.5	37
HVFAC 60%	16	27.3	35
HVFAC 70%	8.08	22.75	30.13
HVFAC 80%	4.13	8.04	18.13

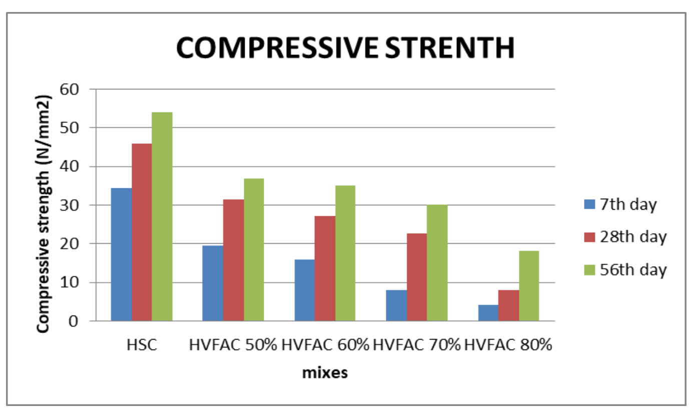


FIG 1
COMPRESSIVE STRENGTH OF CUBES

4.2 Tensile strength of HVFAC AND HSC

Because of the brittle nature of concrete, the tensile strength property is not much important as the compressive strength property. Still, knowing the tensile strength of concrete will help to determine the cracking behavior of member. To determine the tensile strength, split tensile strength test is generally used in laboratories. In this test a standard sized cylinder (150mm diameter and 300mm height) is subjected to a gradually increasing compressive line load along the curved face.

TABLE 8
TENSILE TEST RESULTS

Mix	Avg. Tensile strength in N/mm^2	
	7th Day	28th Day
HSC	2.57	3.48
HVFAC 50%	1.72	2.51
HVFAC 60%	1.59	2.32
HVFAC 70%	1.51	2.28
HVFAC 80%	1.45	2.14

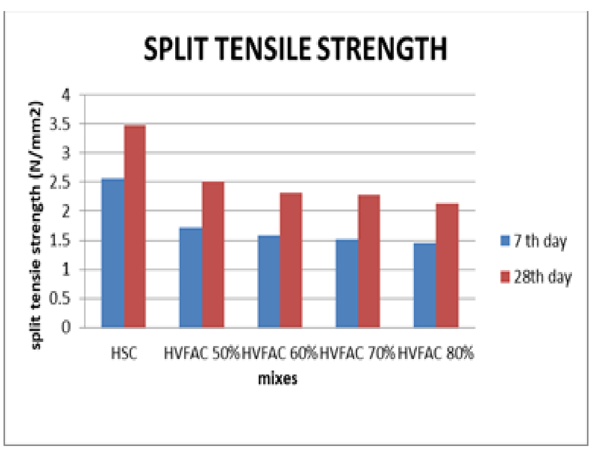


FIG 2 SPLIT TENSILE STRENGTH

Based on the workability, strength, durability requirements high strength concrete having mix proportion of 0.429: 1:1.37: 1.5: 0.015 has been selected. In the case of sacrificial concrete, two type concretes are considered. Because of the low workability and very low strength, concrete with vermiculite as fine aggregate was omitted weight of HVFA is reduced up to 2100 kg/m3. Hence HVFA concrete of mix proportion 0.411: 1: 1.06:1.95 (60% fly ash) and 0.411: 1: 1.05:1.93 (70% fly ash) are selected as sacrificial concrete.

5 DESIGN AND CONSTRUCTION OF BEAMS

The experimental study consists of designing, casting and testing of 7 beams. Beams are in rectangular in shape with cross-sectional dimensions as shown in Figure 5.1 and Figure 5.2 respectively. The total length of beam is 3.2m and the effective length is taken as 3m. Out of twelve beams four were conventional beams and rest of them are hybrid beams. The hybrid beams were cast in such a ways that first type with high strength concrete was used on throughout above the neutral axis and high volume fly ash concrete was used below neutral axis. And second type with the high strength concrete was used on middle third portion above the neutral axis and high volume fly ash concrete was used below neutral axis

5.1 Designing of beams

Hybrid Concrete beams designed as per IS 456:2000 and they are designed as under reinforced sections with minimum reinforcement. Fe500 steel and M35, M20, M15 concretes are used in this project. Both conventional and hybrid beams are designed in the same manner. Because of considering the M20 as sacrificial concrete, only M35 grade was considered for the design of beams. Effective span of the beams are 3.2m, depth and width of beams are 200mm and 150mm respectively.

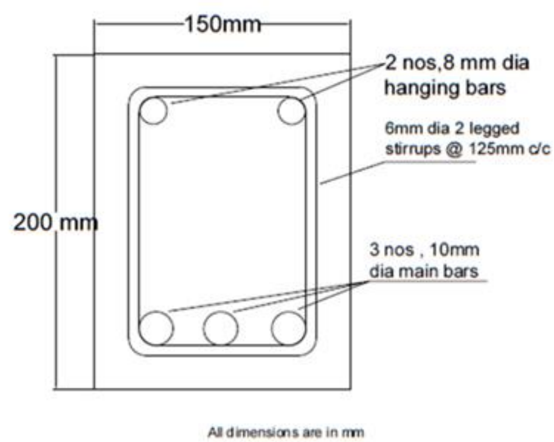


FIG 3
DESIGN DETAILS OF RECTANGULAR BEAM

5.2 Casting and curing of beams

TABLE 9
PROPERTY AND TYPES OF BEAMS

Sl. No	Beam	Property	Type
1	1-I	HSC-Recatgular-M35	Trough out HSC
2	2-I	HC-Rectangular-M35+M20-60% fly ash	Above NA HSC & below NA HVFAC
3	3-1	HC-Rectangular-M35+M20-70% fly ash	Above NA HSC & below NA HVFAC
4	2-II	HC-Rectangular-M35+M20-60% fly ash	Middle third portion above NA HSC other with HVFAC
5	2-III	HC-Rectangular-M35+M20-60% fly ash	Middle third portion above NA HSC other with HVFAC
6	3-I	HC-Rectangular-M35+M20-70% fly ash	Middle third portion above NA HSC other with HVFAC
7	3-III	HC-Rectangular-M35+M20-70% fly ash	Middle third portion above NA HSC other with HVFAC

Model of Hybrid concrete beam which HSC is provided on middle third portion above NA is shown in fig 4. In which the shaded portion indicates HSC and other portion is HVFAC

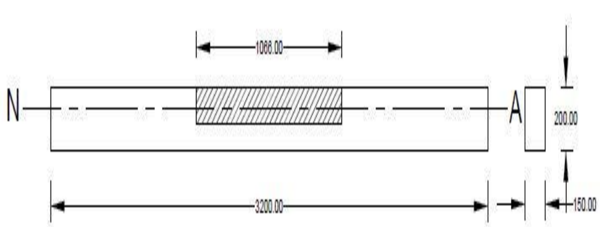


FIG 4
HYBRID CONCRETE BEAM

For hybrid concrete beams, neutral axis was marked in the rectangular beam by a string stretched between two legs of shear reinforcement. High volume fly ash concrete in the tension zone was placed in the formwork in layers. The layers were successively placed one above the other. After the level of string was reached, the concreting operation was stopped with high volume fly ash concrete. Above the string high strength concrete was filled and top of the layer was properly finished to get smooth surface. After one day of casting of beams, wet gunny bags were placed on newly cast rectangular beams.

FIG 5
CASTING OF BEAMS

FIG 6
CURING OF BEAMS

6 TESTS ON BEAMS

The beams were cured for 28 days and test conducted. The cubes were also tested along with the beams. The surfaces of beams were provided with a single coat of white cement for the clear visibility of cracks. To study the behaviour of beams under pure flexure, two point loading system was used on the

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beams. For this an I section and 2 rods of 50mm diameter and 500mm length were used. The schematic diagram of two point loading system is shown in Figure 6.

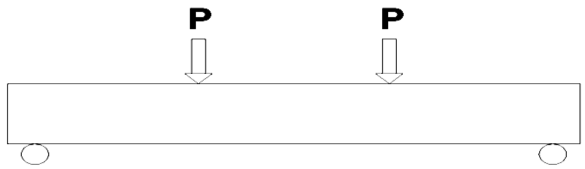

FIG 8
TWO POINT LOADING

FIG 8
TWO POINT LOADING

FIG 9
TEST SETUP OF BEAM

7 TEST RESULTS AND DISCUSSIONS

All beams show flexural cracks at the middle third part of the span according to the loading scheme, and when further load is applied, flexural cracks distributed around the middle part. Their lengths and widths increased. In the sequel, vertical cracks were developed in the shear zone of HC beams. Subsequently, all beams were failed in flexure

7.1 Test results

Flexural cracks were initiated in HC beam earlier than in the HSC beam. Most of the cracks are distributed on middle third portion of the beams. Load at the first crack formation is shown in table 7.1. At the stage of crack initiation, the crack formed in the HSC beams were smaller but in HC beam initial cracks developed towards the neutral axis more quickly. On further loading, new cracks were formed in the HC beam for each increase in load. The crack width in HSC beam was smaller than that of HC beam. Due to sufficient shear reinforcement No shear cracks are appeared until failure.

TABLE 10
LOAD AT FIRST CRACK

Sl. No	Beam	Load at first crack formation (ton)
1	1-I	2.4
2	2-I	2
3	3-1	1.85
4	2-II	1.55
5	2-III	1.65
6	3-I	1.4
7	3-III	1.3

FIG 10
CRACKS ON BEAM

7.2 ultimate load and load-deflection curve

It is observed that HSC beam and HC beam failed under flexure. But the load taken at crack propagation and bending failure are different. Table 7.1, 7.2 shows the load at first crack and ultimate loads. For HSC beam load at first crack is 2.4 ton and at failure it is 4.47 ton. For HC rectangular beam with 60% fly ash in sacrificial concrete load at first crack is 2 ton and at failure 4.23 ton. For HC rectangular beam with 70% fly ash in sacrificial concrete load at first crack is 1.85 ton and at failure 4.11 ton. For HC rectangular beam with 60% fly ash and HSC in middle third portion above NA load at first crack is1.55 ton and at failure 3.91 ton. For HC rectangular beam with 70% fly ash & HSC in middle third portion above NA load at first crack is 1.3 ton and at failure 3.82 ton.

TABLE 11
ULTIMATE LOAD

Sl. No	Beam	Ultimate Load (ton)
1	1-I	4.47
2	2-I	4.23
3	3-1	4.11
4	2-II	3.91
5	2-III	3.79
6	3-I	3.78
7	3-III	3.82

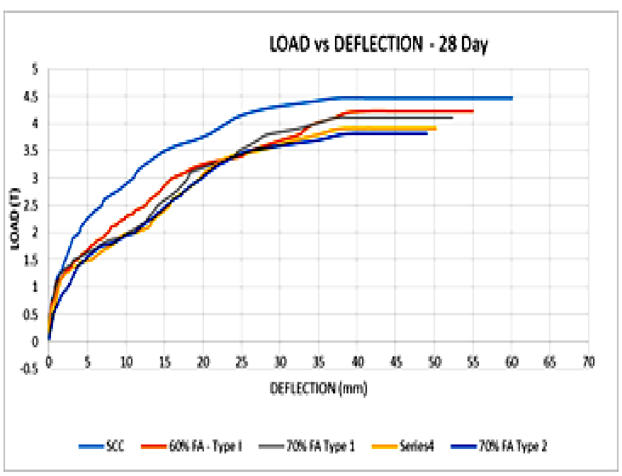

FIG 11
LOAD V/S DEFORMATION CURVE FOR RECTANGULAR BEAM

8 CONCLUSIONS

The ultimate load at failure of HSC beam is greater than that of HC beams. The deflection in HC beams is greater than that of HSC beams. Number of cracks is more in HC beams and Crack width is more in HC at same load. In 60% & 70% fly ash replaced beams, there is not much difference in the ultimate load capacity compared to that of HSC beams. The study leads to the conclusion that using HVFAC in HC beams helps to reduce the usage of cement significantly thus reducing the cost of construction with the added advantage of using a greener concrete.

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