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Experimental Investigation of Micro Particles Incorporated High Volume Fly ash in Reinforced Concrete Beams

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Abstract - *Cement is an essential ingredient in the production of Portland cement concrete. Cement production is a relatively significant source of global carbon dioxide (CO2) emissions, accounting for approximately 4.5% of global CO2 emissions from industry in 2007. Approximately 1 kg of CO2 is emitted for each kg of cement produced. To reduce the CO2 emissions, numerous researchers used supplementary cementitious materials such as fly ash as replacement of cement in concrete. The commonly used SCMs mineral admixtures such as, fly ash, silica fume, metakaolin limestone and slag are widely used due to their availability and significant contribution in improving the concrete properties. Therefore in the present study An experimental investigation was conducted to study both mechanical properties and the flexural strength of reinforced concrete beams constructed with three matrices namely (a)MIX-1(Beam-1) = conventional concrete (CC), (b)MIX-2(Beam-2) = high-volume fly ash concrete (concrete with 50% of the cement replaced with fly ash) and (c) MIX-3(Beam-3) high-volume fly ash concrete incorporated micro particles (concrete with 50% of the cement replaced with fly ash with 4% micro particles 4% micro calcium carbonated). The beams were tested under a simply supported two-point loading condition. The experimental cracking, yielding, and ultimate moments as well as deflection on ultimate load of the beams were calculated. Results of this study showed that the MIX-2 (high-volume fly ash concrete beams) showed decreased strength while MIX-3(high-volume fly ash concrete beams incorporated micro particles) had comparable flexural strength compared with MIX-1 (conventional concrete beams.)*

Key Words: Mechanical Properties, Flexural Strength, High volume Fly ash concrete (HVFAC), Micro calcium carbonate, Micro silica, Reinforced Concrete Beams, supplementary cementitious materials (SCM),

1. INTRODUCTION

In India now a day, the concept of smart city is growing very faster and the main emphasis is development of green and sustainable infrastructure. Smart material is essential to achieve that feat properly, where smart material is one which gives better results in low economy. Currently, researches on sustainable development on concrete have been carried out on following aspects: extension of service life of concrete structure and development of low-carbon concrete material and structure.

Supplementary cementitious materials (SCMs) are being increasingly used in concrete around the world to reduce the amount of cement and improve its properties. The commonly used SCMs mineral admixtures such as, fly ash, silica fume, metakaolin limestone and slag are widely used due to their availability and significant contribution in improving the concrete properties. In the context of sustainability, the replacement of cement by SCMs in concrete is employed to produce environmentally friendly "green concrete" at low cost. Also it contributes to the properties of hardened concrete through hydraulic or pozzolanic activity in which Fly ash acts as pozzolan that reacts with Calcium Hydroxide (CH) due to the presence of amorphous SiO_2 and Al_2O_3 and forms additional Calcium Silicate Hydrate (CSH) gel. This pozzolanic reaction improves the properties of concrete and mortar. Micro-silica in concrete contributes to strength and durability two ways: As a pozzaolanic material, it provides a more uniform distribution and a greater volume of hydration product. As filler, it decreases the average size of pores in the cement paste.

2. Experimental Program

The following section discusses details of mixture proportions, specimen design, test conducted.

2.1 Materials and Mixture Proportions

The following were basic constituents which are used in this investigation.

- Ordinary Portland cement
- Coarse aggregate (CA)
- Fine aggregate (FA)
- Water
- Steel reinforcement (reinforcing bars)
- Class F fly ash
- Micro silica
- Micro Calcium Carbonate

Details of the design Mix proportions and Designation of Test Beam specimen are shown in table 2.1 & 2.2 respectively.

Table2.1 Mix Proportion Details

Test specimen	Cement (%)	Fly ash (%)	MP (%)	Cement (kg/m^3)	Fly ash (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	MP (kg/m^3)	w/c ratio	Water (kg/m^3)
MIX 1	10	0	-	400	0	796	1099	-	0.4	160
MIX 2	70	30	-	280	120	788	1064	-	0.4	160
MIX 3	60	40	-	240	160	772	1043	-	0.4	160
MIX 4	50	50	-	200	200	766	1036	-	0.4	160
MIX 5	50	50	8	200	200	766	1036	32	0.4	160

Table2.2 Designation of Test Beam specimen

Design Mix	Mix Proportion
B-1	Conventional concrete
B-2	50%Cement+50%Fly ash
B-3	50%Cement+50%Fly ash+4%MS+4%MC

Table 2.3 Materials required for each test Beam specimen

Mix symbol	Cement (Kg)	Fly ash (Kg)	Micro silica (Kg)	Micro calcium carbonate (Kg)	Fine aggregates (Kg)	Course aggregates(Kg)	Water (Ltr)
B-1	12.22	Nil	Nil	Nil	24.1	31.9	4.9
B-2	13	13	Nil	Nil	49.14	65.26	10.4
B-3	13	13	2.08	2.08	49.14	65.26	10.4

2.2. Specimen Design

The experimental studies include casting and testing of 45 test cube specimens for compression test, 45 prism specimens for flexural test, 45 cylinders for split tensile. The tests were conducted as per the Indian Standard code of Practice as mentioned below.

- **Compression test on standard specimen (Cube,** As per IS: 516:1959, *Clause 5.1 up to 5.6***)**
- **Flexural test on standard specimen (Prism,** As per IS: 516:1959**)**
- **Split tensile test on standard specimen (Cylinder,** As per IS: 516:1959**)**

For static load studies 6 test beam specimens are casted. Each test beam specimen had 4 no's of 12mm dia HYSD Fe-550 bars. All test beam specimens had identical geometrical properties with different proportionate of concrete as mentioned in table 2.3. The casted specimens for testing are shown in fig 2.1 and geometry reinforcement arrangement of test beam specimens is shown in fig 2.2.

Fig 2.1 specimens casted for testing

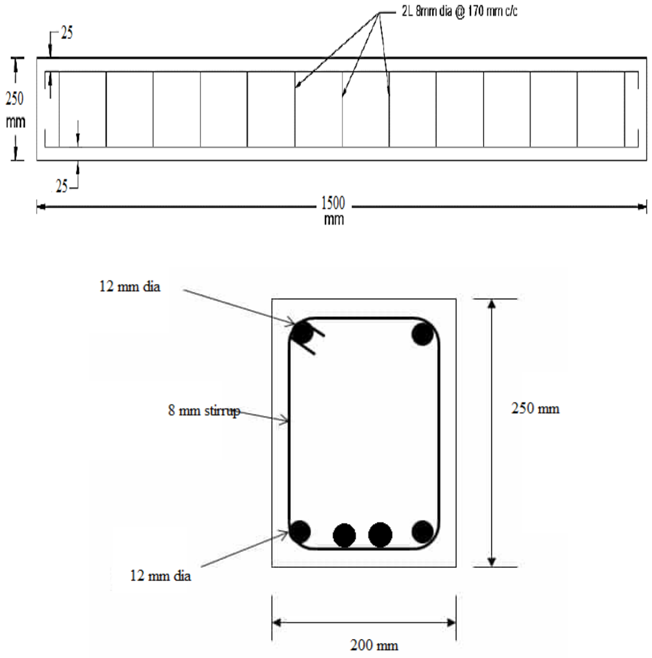

Fig 2.2 Geometry Reinforcement Arrangement of Test Beam Specimens

2.3. Test conducted

i. Compressive strength test

Compressive strength of any material is defined as the resistance to failure under the action of compressive forces. Especially for concrete, the compressive strength is an important parameter to determine the performance of the material during service conditions. The compression test is carried out on specimen cubical in shape of size 150×150×150mm.

Compressive Strength = P/A

Where, P= Maximum Load

A= Area of the mould

ii. Flexural Strength test

Flexural strength of the concrete also known as modulus of rupture or bend strength or transverse rupture strength is a material property, defined as stress in a material just before it yields in a flexure test. The strength of concrete for flexural members is commonly evaluated by means of bending tests on 100 mm x 100 mm x 500 mm beam specimens.

Calculations:

The Flexural Strength or modulus of rupture if given by

a) If the fracture occurs within the middle third of the span, a>133 mm

Fb=$PLbd2$ (when a >13.3cm for 10.0 cm specimen)

b) If the fracture occurs outside the middle third but deviating by not more than 5 percent of the span length, 110 < a < 133mm

Fb=$3Pabd2$ (when a<13.3 cm for 10.0 cm specimen)

c) If fracture occurs by more than 5 percent outside the middle third, a < 110mm, then the results of the test should be rejected.

Where a = the distance between the line of fracture and the nearer support, measured on the center line for the tensile side of the specimen.

b= width of specimen (cm) l=supported length (cm)

d= failure point depth (cm) P= maximum load (kg)

iii. Split tensile strength

Split tensile strength of concrete can be defined as a method of determining the tensile strength of concrete using cylinder which splits across the vertical diameter. It is an indirect method of testing tensile strength of concrete. The cylindrical specimen of size 150 mm Φ x 300 mm is used.

σ_{sp}= $2P\Pi dl$

Where σ_{sp} = Spilt tensile strength of concrete in N/mm2

P = Load causing rupture in N,

d = Diameter of cylinder in mm

L = Length of cylinder in mm.

iv. Static Bending Test

The purpose of conducting the static bending test for Beam specimens under monotonic loading until ultimate stage is

- To study the load deflection curve.
- To investigate ductility index, energy absorption and toughness index characteristics computed from the area of the load deflection curve.
- To study the crack pattern, first crack load and ultimate load.

Static Testing Machine

Static testing machine which is used in the present investigation is fabricated and installed at Department of Civil Engineering Bangalore University, Bengaluru. It is a manual operated hydraulic jack system and was rigidly fixed to an RCC pedestal foundation to a height of 0.3 m above ground level and the pedestal was extended up to 0.7 m giving it total height of 1 m, to which a frame of height 2.5 m fabricated with I-sections of ISMB 250 and is mounted. The loading assembly is supported vertically by a horizontal I-section of ISMB 250. Schematic diagram for Static test on beam is as shown in fig 2.3.

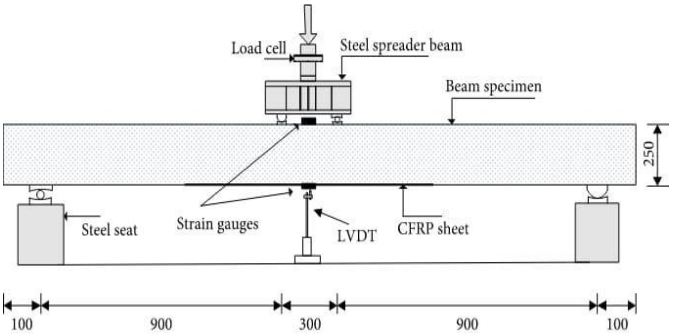

Fig 2.3 Schematic diagram for Static test

3. Results and Discussions

a) Results on Compressive Strength

Table 3.1- 7, 14, 28 days compressive strength on cubes

	Compressive Strength (N/mm2)		
Designation	**7 Days**	**14 Days**	**28 Days**
MIX1	29.33	37.18	45.92
MIX2	26.98	35.41	37.04
MIX3	24.60	19.26	27.26
MIX4	14.22	18.07	21.11
MIX5	18.22	25.04	29.04

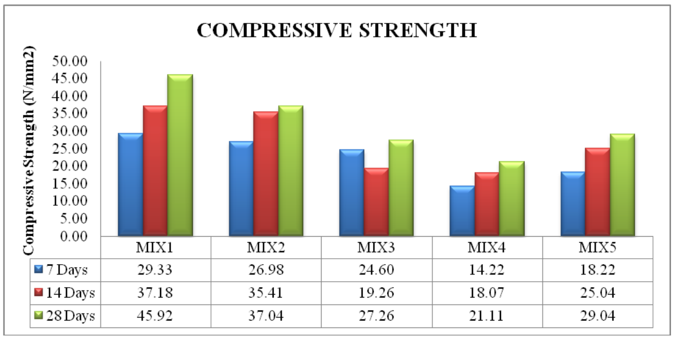

Fig 3.1 Compressive strength comparison with age of different concrete matrices

b) Results on Flexural strength

Table 3.2- 7, 14 and 28 days flexural strength on prisms

Flexural Strength (N/mm2)			
Designation	**7 Days**	**14 Days**	**28 Days**
MIX1	5.40	5.6	6.8
MIX2	4.40	5.33	7.13
MIX3	3.07	4.05	6.53
MIX4	2.67	3.2	3.89
MIX5	2.93	4.67	5.2

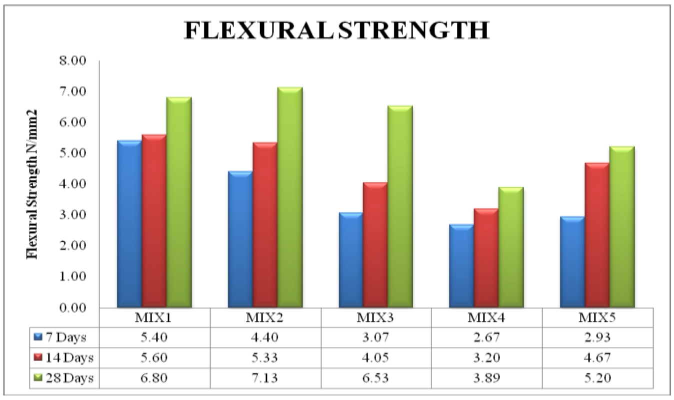

Fig 3.2 Flexural strength comparison with age of different concrete matrices

c) Results on split Tensile strength

Table 3.3- 7, 14 and 28 days split tensile on cylinders

Split Tensile strength (N/mm2)			
Designation	**7 Days**	**14 Days**	**28 Days**
MIX1	3.91	4.9	5.8
MIX2	2.30	2.59	3.44
MIX3	1.41	1.79	2.64
MIX4	0.85	1.6	1.93
MIX5	0.85	1.6	1.95

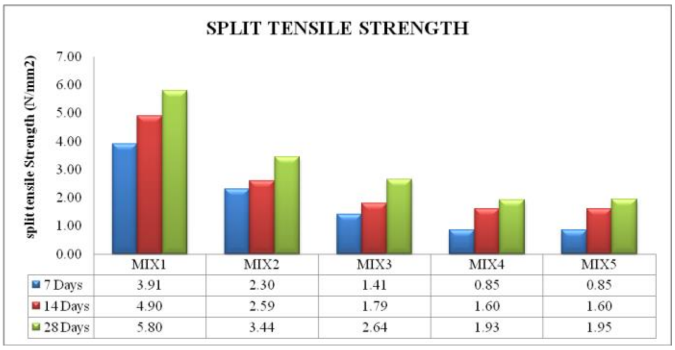

Fig 3.3 Split tensile comparison with age of different concrete matrices

d) Result on Static Bending test

- Load Deflection curves

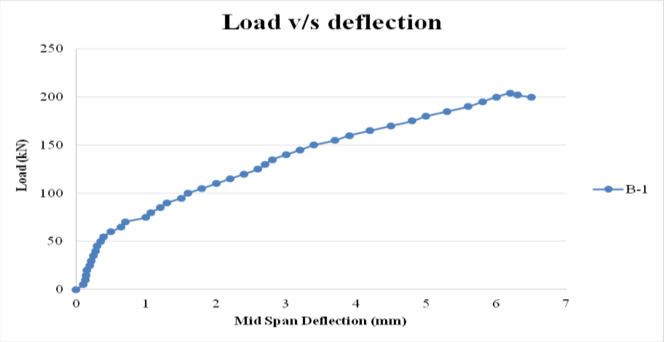

Fig 3.4 Load - Deflection curve for B-1

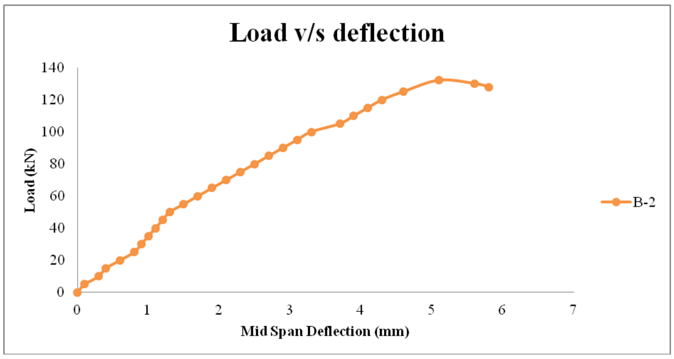

Fig 3.5 Load - Deflection curve for B-2

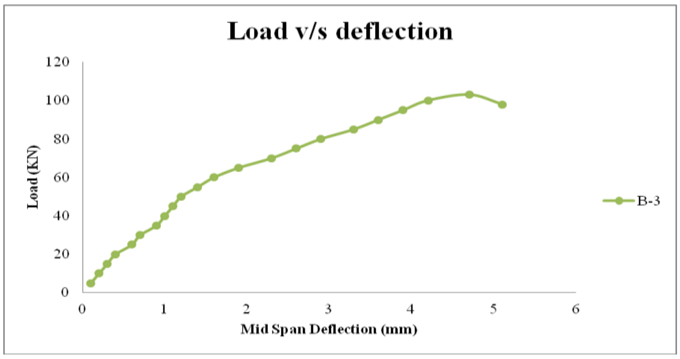

Fig 3.6 Load - Deflection curve for B-3

- **First crack load (kN)**

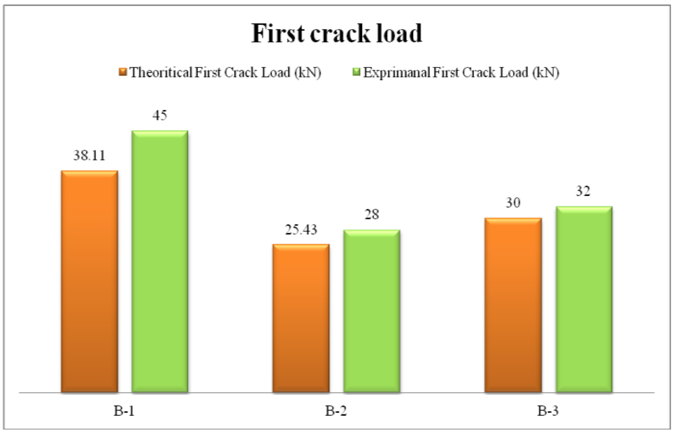

Fig 3.7 First Crack load

- **Ultimate load (kN)**

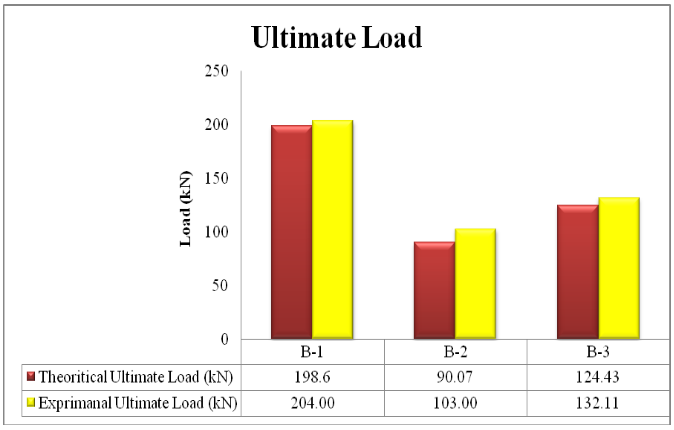

Fig 3.8 Ultimate load

- **Yield deflection variations (mm)**

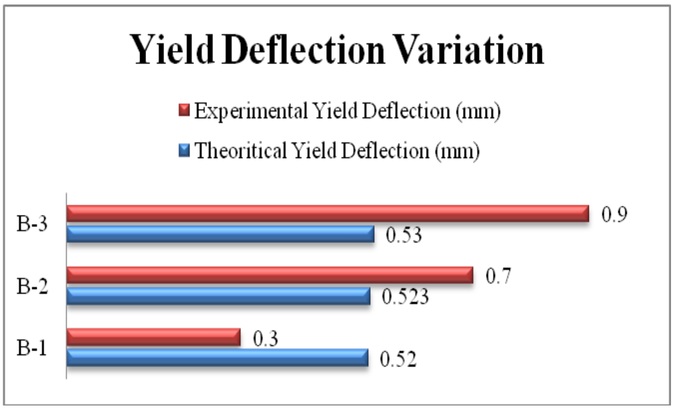

Fig 3.9 Yield Deflection varitaion

- **Ultimate deflection variation (mm)**

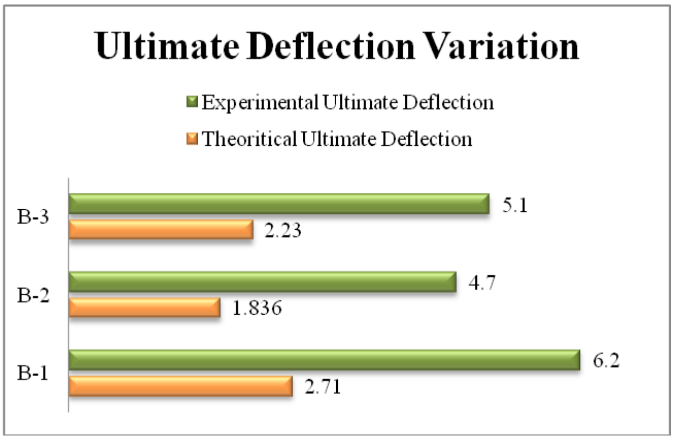

Fig 3.10 Ultimate deflection variation

- **Ductility Index**

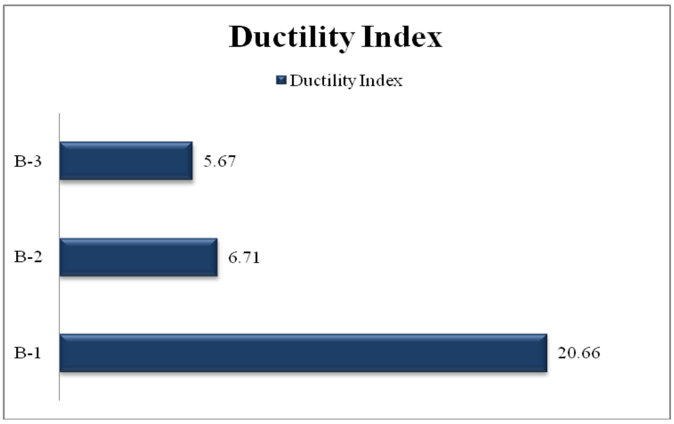

Fig 3.11 Ductility Index

- **Energy Absorption Capacity (kN-mm)**

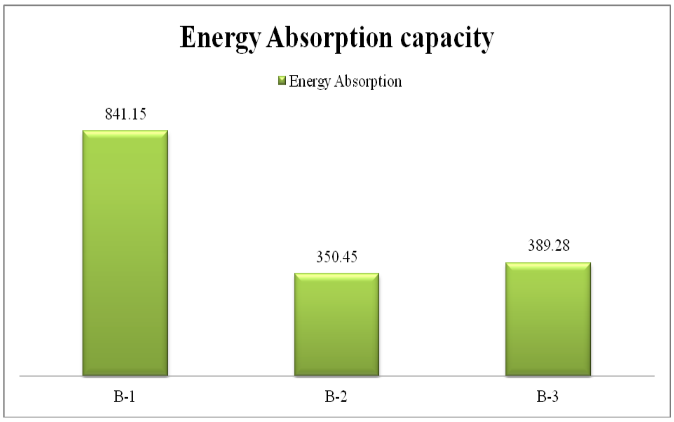

Fig 3.12 Energy Absoption Capacity

- **Toughness Index**

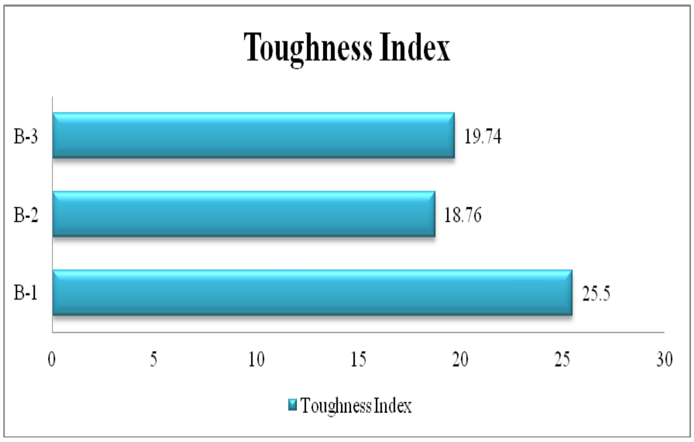

Fig 3.13 Toughness Index

- **Crack Pattern**

The evaluation of crack widths is strongly related with durability aspects of building structure. Cracking assessment is commonly limited to load cases considered for serviceability requirements. Cracking in reinforced concrete beams subjected to bending usually starts in the tensile zone i.e. soffit of the beam. The width of flexural cracks in reinforced concrete beams for short-term may stay narrow from the surface to the steel. However, in long-term under continuous loading, the width of crack may get increased and become more uniform across the member. During the initial stage of loading no beam showed cracks but as the load increases above the yield load the cracks started. The cracks patterns for different mixes are shown in the figure 3.15.

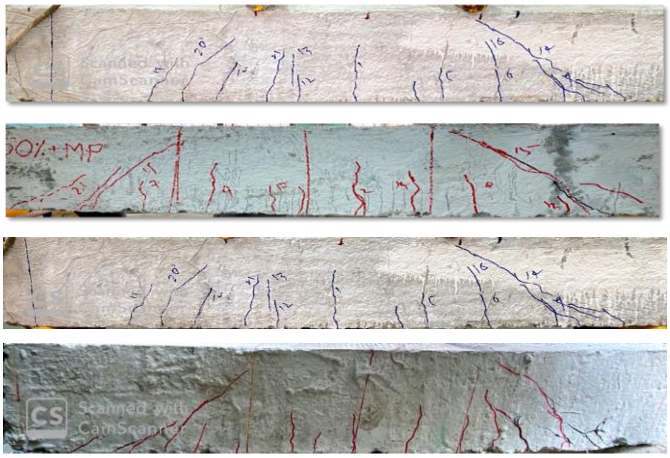

Fig 3.16 Crack Pattern

4. CONCLUSIONS

Mechanical properties of the concrete

- **Compressive strength of concrete**

The experimentally obtained values of the compressive strength at 28 days for MIX-1 concrete is 45.92N/mm^2, MIX-2 is 37.04N/mm^2 and MIX-3 is 27.26N/mm^2 whereas for MIX-4 and MIX-5 compressive strength is found to be 21.11N/mm^2 and 29.04N/mm^2 respectively which is comparable to the target strength calculated as per IS 10262-2009. It is observed that from experimental results, compressive strength for MIX-2, MIX-3, MIX-4 and MIX-5 has achieved 80.66%, 59.36%, 45.98% and 63.24% compared to MIX-1.

- **Flexural Strength of concrete**

The experimentally obtained values of the bending strength at 28 days for MIX-1 concrete are 6.8N/mm2, MIX-2 is 7.13N/mm2 MIX-3 is 6.53N/mm2 whereas for MIX-4 and MIX-5, the bending strength is found to be 3.89N/mm2 and 5.2N/mm2 respectively. It is observed that from experimental results, bending strength for MIX-2, MIX-3, MIX-4 and MIX-5 has achieved 104.85%, 96.03%, 57.21% and 76.47% of control Mix strength respectively

- **Splitting Tensile Strength**

The experimentally obtained values of the splitting tensile strength at 28 days for MIX-1 concrete are 5.80N/mm^2, MIX-2 is 3.44N/mm^2 and MIX-3 is 2.64N/mm^2 whereas for MIX-4 and MIX-5, the splitting tensile strength is found to be 1.93N/mm^2 and 1.95N/mm^2 respectively. It is observed that from experimental results, bending strength for MIX-2, MIX-3, MIX-4 and MIX-5 has achieved 59.31%, 45.52%, 33.28% and 33.62% of control Mix strength respectively.

Here we can see clearly that in economical view of saving concrete by replacing 50% of cement with high volume fly ash, there is reduction in the mechanical properties of the concrete but it can be raised by the addition of micro-particles.

Static Bending Test of Beam specimens

- **Load deflection curve**

All the concrete slabs showed linear deflection to certain extent which is considered an ultimate load of specimen beyond this point a nonlinear variation was observed, where as fly ash concrete incorporated beams showed more deflection than the Normal concrete slabs at a given load.

- **First crack load**

The experimentally obtained values of first crack load for B-1 is 45 kN whereas for B-2 and B-3 and are 28 kN and 32 kN respectively. It is observed that from experimental results, first crack load for other beams as achieved upto 62.23% and 71.11% with respect to control beam B-1.

- **Ultimate Load**

The experimentally obtained values of ultimate load for B-1 is 204 kN whereas for B-2 and B-3 are 103 and 132.11 kN respectively. It is observed that from experimental results, ultimate load for B-2 and B-3 beams have achieved up to 50.49% and 64.75% respectively with respect to control beam B-1.

It is experimentally evident that for test beam specimen B-3, ultimate load has been significantly achieved up to 64.75% in comparison with B-1.

- **Yield deflection variation**

The experimentally obtained values of yield deflection for B-1 is 0.52mm whereas for B-2 and B-3 are 0.523mm and 0.53mm respectively. It is observed that from experimental results, yield deflection for other beams is 100.1% and 101.92% with respect to control beam B-1.
It is experimentally evident that for Beam B-3 first crack deflection is equal to Beam B-1.

- **Ultimate deflection variation**

The experimentally obtained values of ultimate deflection for B-1 is 6.2mm whereas for B-2 and B-3 are 4.7mm and 5.1mm respectively. It is observed that from experimental results, ultimate deflection for other beams is 75.80% and 82.25% with respect to control beam B-1.
It is experimentally evident that for Beam B-3 ultimate deflection has been significantly enhanced to 17.74% in comparison with Beam B-1.

- **Ductility Index**

From the results it can be seen that Ductility Index for B-2 and B-3 is achieved up to 32.47 % and 27.44% w.r.t beam B-1 respectively also Ductility Index for B-3 is achieved higher value w.r.t B-1 than all other concrete matrices.

- **Energy Absorption Capacity**

The experimentally obtained values of Energy absorption capacity B-1, B-2 and B-3 concrete test beam specimens are 841.15kN-mm, 350.45kN-mm and 389.28kN-mm respectively. It is observed that from experimental results, energy absorption capacity for B-2 and B-3 has been achieved up to 41.66% and 46.27% respectively with respect to control beam B-1.

- **Toughness Index**

From the results it can be seen that toughness index is achieved w.r.t B-1 by 77.41% and 73.56% for B-2 and B-3 test beam specimens respectively.
It is observed that the Toughness Index for Beam B-2 is achieved higher value w.r.t Beam B-1 than all other concrete beam Specimens.

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