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# Experimental Investigation on HPFRC Beams Subjected to Cyclic Loading

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***Abstract* - Concrete is most widely used construction material. Because of its specialty of being cast in any desirable shape, it has replaced stone and brick masonry. In spite of all this, it has some serious deficiencies such as lack of tensile strength, ductility etc. To improve the deficiencies steel fibres are added to the concrete, known as fibre reinforced concrete which is an emerging technology used in the construction industry. Fibre reinforced concrete is a concrete containing fibrous material which increases its structural integrity. It contains short discrete fibres that are uniformly distributed and randomly oriented. The addition of steel fibres to cement concrete leads to improvement in several properties of concrete.**

**In this project the behaviour of HPFRC are studied and compared with conventional beams. Totally four numbers of beams were cast and tested for its cyclic behaviour. The specimen is incorporated with Hooked End and Crimpled fibres in the mix proportion of 70%-30% by volume at a total volume fraction of 1.5%. Silica fume and super plasticizers are added to modify the properties of concrete. The beams were subjected to single point cyclic loading by means of screw jack and the deflection is measured by using dial gauge. The load deflection behavior for all the beams were drawn and the important parameters like load carrying capacity, ductility, energy absorption, stiffness, first crack load and ultimate load has been studied and compared with other specimens.**

## INTRODUCTION

Due to enhanced mechanical properties such as strength, stiffness, toughness, ductility and durability, high performance concrete has gained wider acceptance in the construction of tall buildings, long span bridges, high rise building, off shore structures and other mega structures.

For past few decades, HPC has undergone many developments based on the influence of cement type, type and proportions of mineral admixtures, types of super plasticiser and the composition of coarse and fine aggregate. It is commonly accepted that the properties of an aggregate used in HPC have great influence on structural properties and on durability.

## FIBER REINFORCED CONCRETE

Fibre reinforced concrete is a concrete mix that contains short distance fibres that are uniformly distributed and randomly oriented. As a result of these different formulations, four categories of fibre reinforcing have been created; these include steel fibre, glass fibres, synthetic fibres and natural fibres. Within these different fibres that character of fibre reinforced concrete change with varying concrete's, fibre materials, geometries distribution, orientation and densities.

The amount of fibres added to a concrete mix is measured as a percentage of total volume of the composite termed volume fraction (Vf). Vf typically ranges from 0.1 to 3%. Aspect ratio (1/d) is calculated by diving fibre length (l) by its diameter (d).

Applications of Fibre Reinforced Concrete

- FRC is used as crack control and shrinkage for water retaining and reservoir structure to reduce the permeability and freeze-thawing conditions.
- Increase of toughness in fibre reinforced concrete is ideal for building and pavements subjected to shatter-impact abrasion and shear.
- FRC has also been used in beam- column junction and penetration and impact resistance are found to be very high for FRC when compared to other materials.
- FRC replaces the temperature steel in sanitary sewer tunnels which prevents corrosion and improves ductility.
- FRC is used in repairs and rehabilitation of marine structures such as concrete pilling and caissons.

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## HIGH PERFORMANCE FIBR REINFORCED CONCRETE

High performance concrete (HPC) is a recent development in concrete technology. It is designed to give optimized performance characteristics for the given set of materials, usages and exposure conditions with requirements of with requirements of cost, service life and durability. Development of HPC is directly related to a number of recent technological developments, in particular the discovery of the extraordinary dispersing action of super plasticizers, use of micro fillers like silica fume increasing availability of fibres of different types and properties etc. The use of chemical admixtures in HPFRC reduces the water content, thereby reducing the porosity within the hydrated cement paste. It has been proved that steel fibres can be used to control cracking and deflection in concrete structural members. Addition of steel fibres to HPC makes it highly ductile and improves the energy absorption capacity.

*Properties of HPFRC*

- Significantly improved fatigue resistance
- Increased load bearing capacity and less palling damage
- Durability can significantly improve
- It increases the load carrying capacity and provides uniform multi-directional reinforcement in concrete
- It reduces the plastic shrinkage and thickness of concrete slab
- It improves the impact resistance and shear strength
- It resists abrasion and toughness
- Excellent crack control, the fibres control and settles cracks
- It improves ductility and controls the sudden deformation

## SCOPE OF PRESENT INVESTIGATION

The objective of the present investigation is to compare the behaviour of hooked end fibre reinforced concrete beams, crimpled fibre reinforced concrete beams, hybrid fibre reinforced concrete beams with conventional high performance reinforced concrete beams.

The properties such as energy absorption, stiffness, ductility factor, first crack load, ultimate load are also studied in this investigation.

## METHODOLOGY

- Testing of HPC Concrete beams(i.e) HPC 1, HPC 2.
- Testing of HPFRC Concrete Beams
  - Hooked
  - Crippled
  - Hooked + Crippled
- Testing under cyclic loading
- Comparision of results of HPC beams with HPFRC beam.

## EXPERIMENTAL INVESTIGATION

The HPFRC material consists of steel fibres, silica fume, super plasticizer, reinforcing steel and cement materials. The behaviour of HPFRC material is studied through an experimental programme. Four beam such as Hooked end fibre reinforced concrete beam, Crimpled fibre reinforced concrete beam, Hybrid fibre reinforced concrete beam and Conventional high performance reinforced concrete beams were cast and tested. All the beams were simply supported at both ends with concentrated point loading system and the beams are subjected to cyclic loading.

*Coarse aggregate*

The coarse aggregate used in the mixes were 12mm and 10mm are mixed in the proportions of 60% - 40%. The specific gravity of coarse aggregate was determined and found to be 2.8.

*Steel*

The main reinforcement used for the beams were high yield strength deformed steel bars of 8mm and 6mm diameter deformed bars were used for shear reinforcement.

*Super plasticizers*

Cera hyperplast XR-W40 is an acrylic polymer based new range water reducing admixture. In this project we are using 0.8% of Super plasticizers.

*Silica fume*

In this project we are using 10% of silica fume by replacing the cement. It is extremely fine with particle size less than 1 micron. The silica fume increases the bond strength between cement paste and aggregate and it will fills the micro pores present in aggregate.

*Steel fibers*

In this speciemen is in incorporated with hook end fibre and crimpled fibre are used separately and mixed in the mixpropotion of 30% - 70% by volume at total volume fraction of 1.5%

*Mix Design*

M60 grade of concrete has been designed as per IS code and the mix proportions is given in the table

Water - 0.3
Cement - 1
Fine aggregate - 1.2
Coarse aggregate – 2.2

*Reinforcement details*

The beams were cast with the following reinforcement details 4 numbers of 8mm diameter rods was used as main reinforcement, 2 numbers at top and 2 numbers at bottom. 6mm diameter stirrups spaced at 100mm centres were used as shear reinforcement. The reinforcement details are shown in the figure

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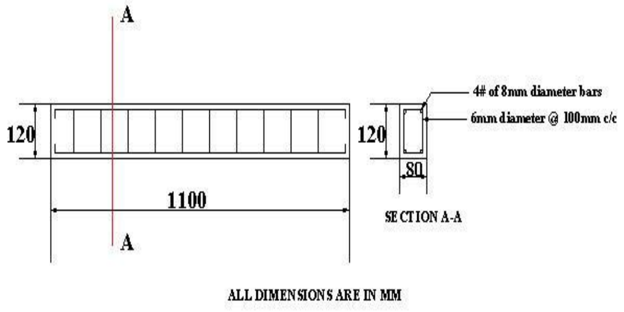



EXPERIMENTAL PROGRAMME

*Casting of specimen*

The materials were weighted accurately using digital weighing instrument. For HPC cement, fine aggregates, coarse aggregates, water and superplasticzers were added to mixture manually and mixed thoroughly in a concrete mixture and for HPFRC Hooked end fibre & crimpled fibre are used separately and also mixed in the mix proportion of 30% to 70%. The concrete is mixed in three layers in the mould & compacted manually.

CURING OF SPECIMENS

The beams were kept in mould for 24 hours. After that they were marked for future identifications. Then the side plates of the beam mould were removed and the test specimen was transported to the curing pond. The specimens were taken out of the water after 28 days and dried out before testing

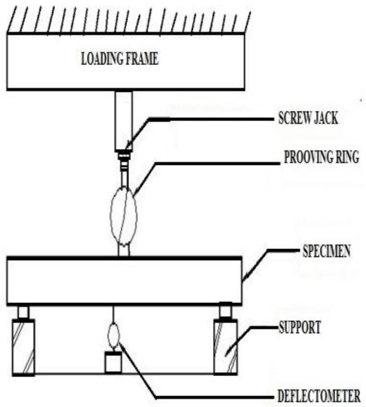
*Experimental Setup*

The beams were simply supported at both ends and were tested for central concentrated cyclic loading. The load was applied using screw jack. Small thin glass plates were fixed to the bottom surface of the beam to provide smooth surfaces where deflections are to be measured. The deflectometer was fixed at the bottom of the beam for measuring the deflection in the beam. A proving ring was fixed below the hydraulic jack to measure the applied load on the beam. The complete experimental setup is represented in figure

EXPERIMENTAL RESULTS AND DISCUSSIONS

❖ *Load Deflection Behaviour*

The beams are subjected to cyclic loading by using screw jack. No of cycles of loading were imposed on the beam till it fails. The deflections are measured at the centre of beam by using deflectometer.




*Experimental Setup*

❖ *Load Deflection Behaviour*

The beams are subjected to cyclic loading by using screw jack. No of cycles of loading were imposed on the beam till it fails. The deflections are measured at the centre of beam by using deflectometer.

❖ *First Crack Load*

In general, the beams subjected to loading will develop crack gradually with increase in load. The initial load at which the crack formed is known as first crack load.

❖ *Ultimate Load*

Ultimate load is defined as the maximum load at which the beam can withstand its position without any failure. When compared to conventional concrete beams, the fibre reinforced concrete will have maximum load carrying capacity.

❖ *Stiffness*

Stiffness is defined as the load required causing unit deflection of beam. A tangent was drawn for each cycle of the hysteresis curves at a load of P = 0.75 Pu.

❖ *Relative Energy Absorption Capacity*

When the frame is subjected to cyclic loading such as those witnessed during wind or earth quake loads some energy is absorbed. It is equal to the work done in straining and deforming the structure to the limit of deflection. The relative energy absorption capacities during various load cycles were calculated as the area under the hysteresis loops from the load versus deflection diagram. The cumulative energy absorption capacity of the frame was obtained by adding the energy absorption capacity of the frame during each cycle considered.

❖ *Ductility Factor*

Ductility is one of the most important parameter to be considered in the design of structures subjected to various loading conditions. It is defined as the ability of a member undergoes inelastic deformations beyond the yield deformations without significant loss in its load carrying capacity. The ductility of a flexural member can be obtained from its load-deflection curve. The ratio of maximum deflection at each cycle to the deflection at first yield is known ductility factor.

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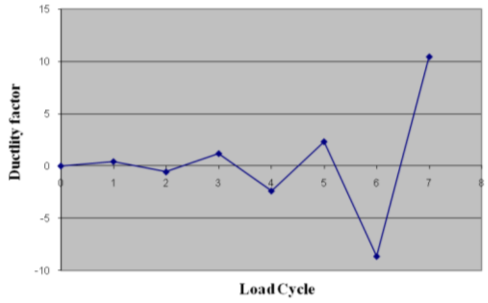
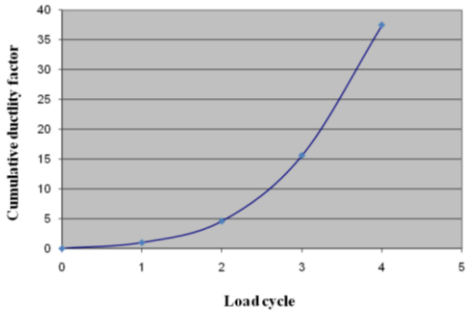
# RESULTS AND DISCUSSION

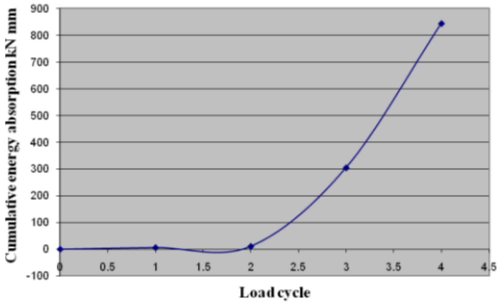
## Behaviour of conventional concrete beam



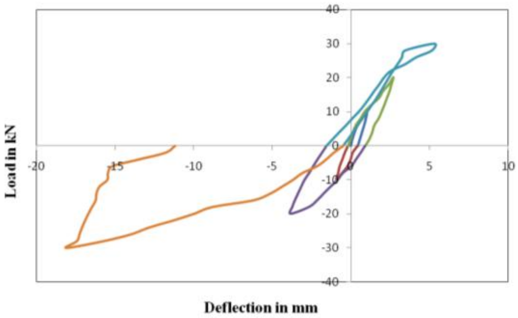

Variation of Ductility Factor with Load Cycle




Variation of cumulative ductility factor with load cycle

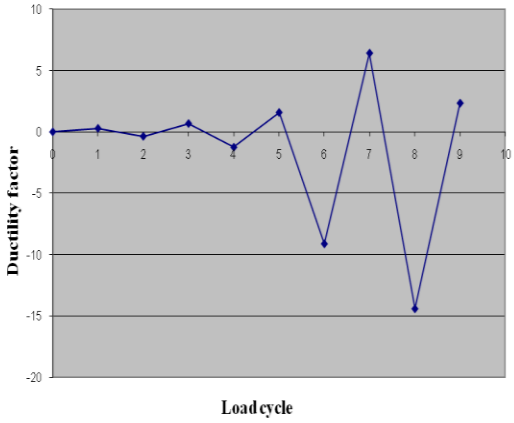



Variation of Cumulative Energy Absorption with Load Cycle

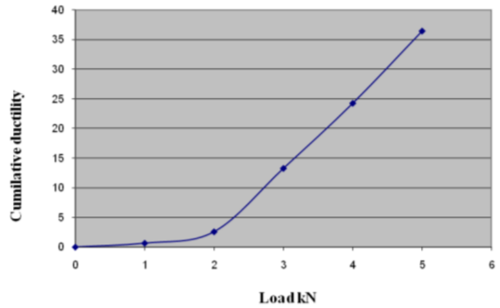



*Loop Diagram For HPC Beam*

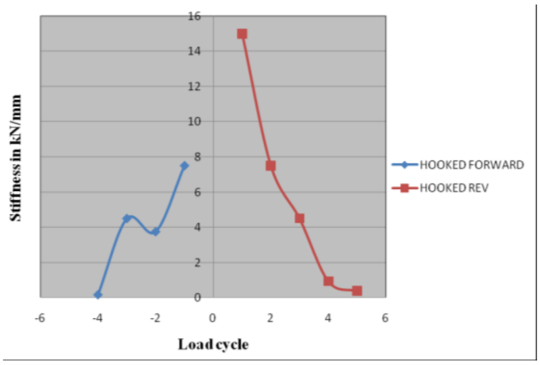
## BEHAVIOUR OF HOOKED END FIBRE RC BEAM




Variation of Ductility Factor with Load Cycle




Variation of Cumulative Ductility Factor with Load




Variation of Stiffness with Load Cycle

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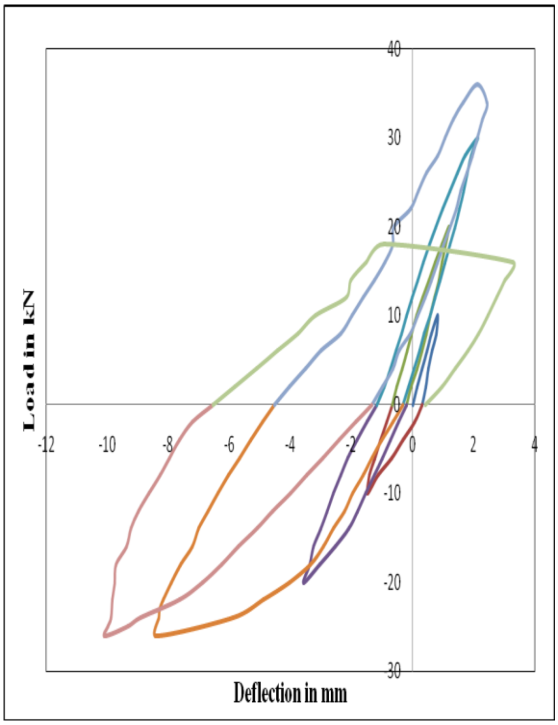
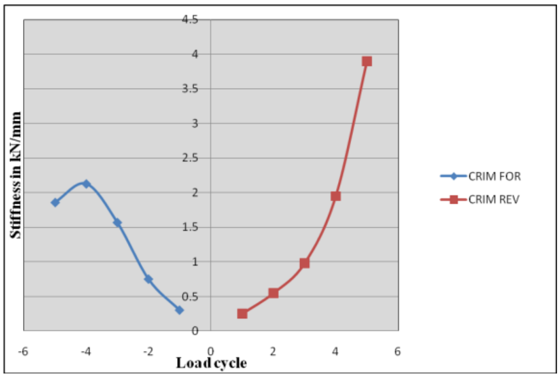
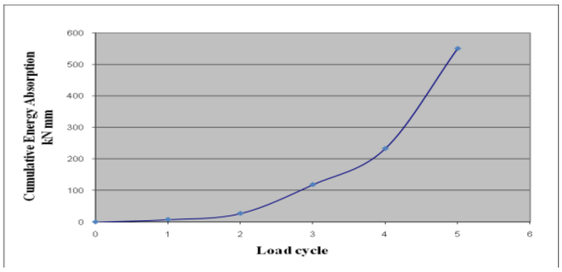



Loop Diagram for Hooked End Fibre Beam

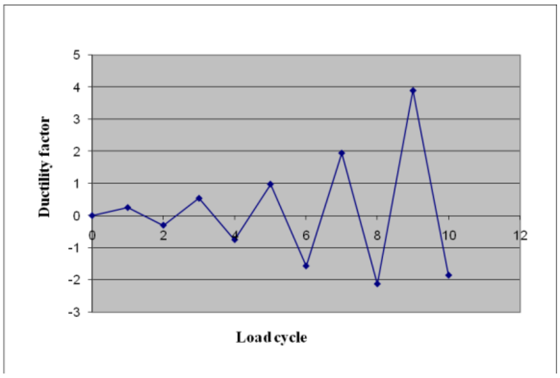



Variation of Stiffness with Load Cycle

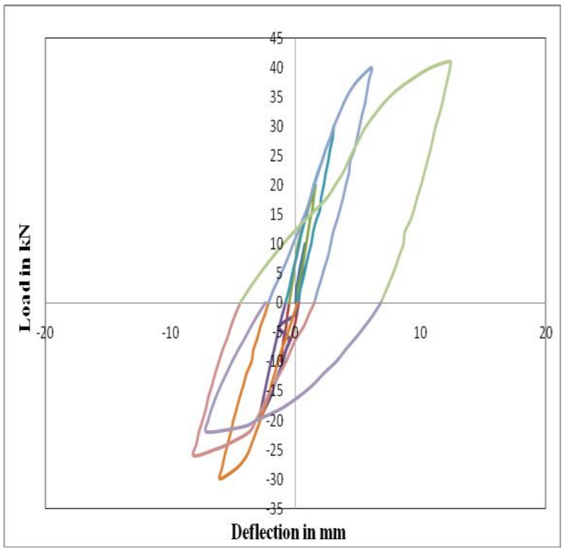



Variation of Energy Absorption with Load Cycle

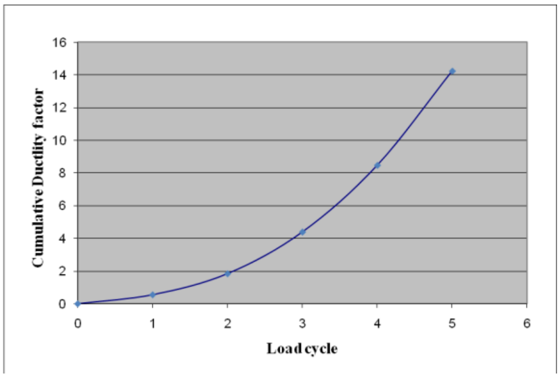
## BEHAVIOUR OF CRIMPLED FIBRE RC BEAM




Variation of Ductility Factor with Load Cycle

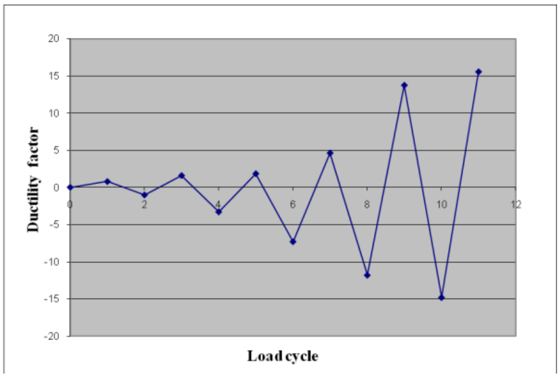



Loop Diagram for Crimpled Beam

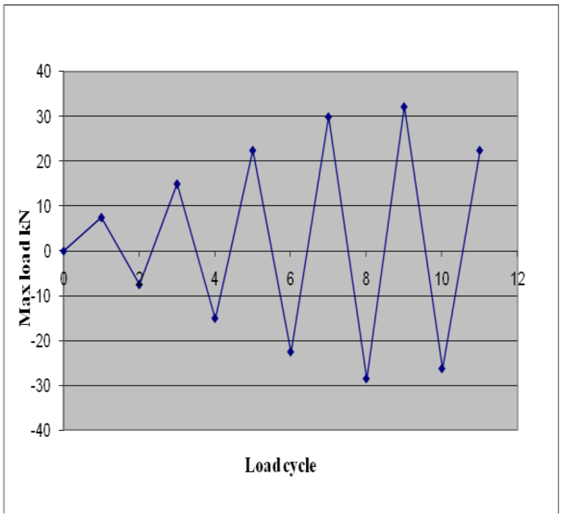



Variation of Cumulative Ductility Factor with Load

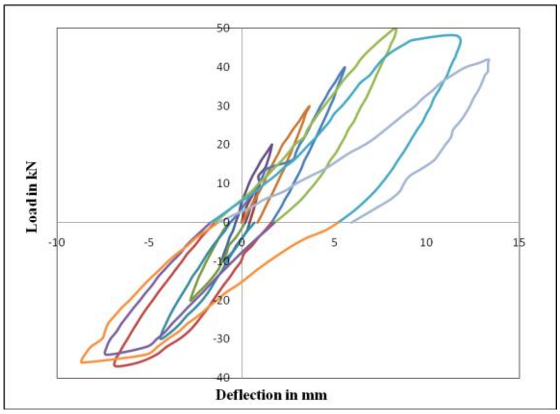
## BEHAVIOUR OF HYBRID FIBRE RC BEAM




Variation of Ductility Factor with Load Cycle




Load Sequence Diagram




**Loop Diagram for Hybrid Beam**

## COMPARISON OF TEST RESULT

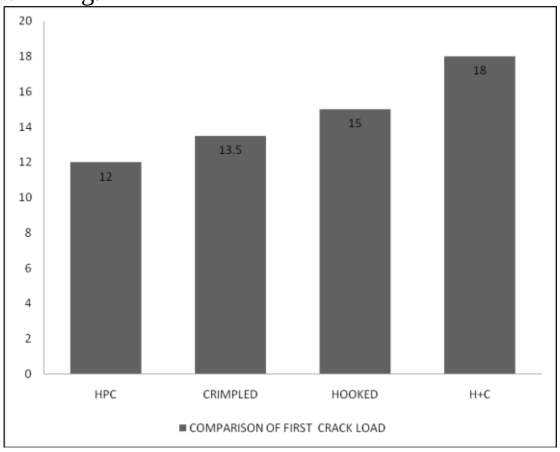
*Comparison of Beams*

In this project, the beams are compared with various parameters such as first crack load, ultimate load, cumulative ductility factor and energy absorption. The different parameters of conventional RC beam, hooked end, crimpled and hybrid fibre reinforced concrete beam were shown in Table

| SNO | PARAMETER | HPC | H | C | H+C |
|---|---|---|---|---|---|
| 1 | First Crack Load (kN) | 12 | 15 | 13.5 | 18 |
| 2 | Ultimate Crack Load (kN) | 22.5 | 27 | 30.25 | 32.25 |
| 3 | Stiffness (kN/mm) | 3.74 | 4.19 | 4.24 | 4.89 |
| 4 | Ductility Factor | 14.68 | 36.42 | 16.48 | 76.11 |
| 5 | Energy Absorption (kN mm) | 550 | 1213 | 844.5 | 1312.5 |

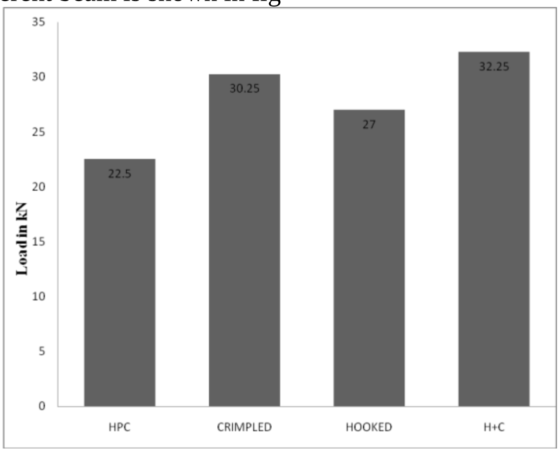
## COMPARISON OF FIRST CRACK LOAD

The first crack load for the conventional RC beam, hooked end, crimpled and hybrid fibre reinforced concrete beam were 12kN, 13.5kN, 15kN and 18kN respectively. The first crack load for the hybrid fibre reinforced concrete beam was 1.5 times greater than conventional RC beam. The graphical representation for the comparison of first crack load for different beam is shown in fig.




## COMPARISON OF ULTIMATE LOAD

The ultimate load carrying capacity of the conventional RC beam, hooked end, crimpled and hybrid fibre reinforced concrete beam were 22.5kN, 30.75kN, 27kN, 32.25kN respectively. The ultimate load for the hybrid fibre reinforced concrete beam was 1.45 times greater than conventional RC beam. The graphical representation for the comparison of ultimate load for different beam is shown in fig




## COMPARISON OF CUMULATIVE DUCTILITY FACTOR

Ductility is defined as the ability of a member undergoes inelastic deformations beyond the yield deformations without significant loss in its load carrying capacity. The ratio of ultimate deflection to the deflection at first yield is known was ductility factor. In this experiment, hybrid reinforced concrete beam will give maximum ductility when compare to conventional concrete beam. The comparison of cumulative ductility factor for different type of beam is shown in

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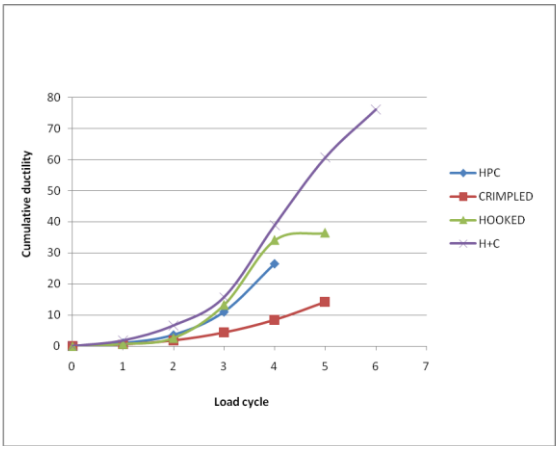
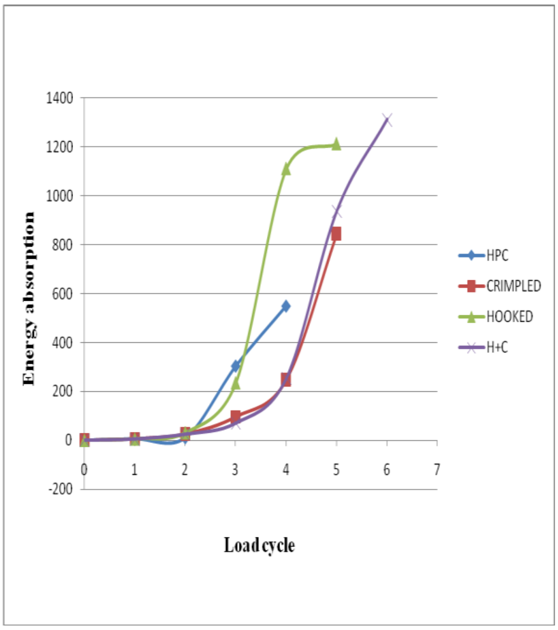



COMPARISON OF ENERGY ABSORPTION

The cumulative energy absorption capacity of the frame was obtained by adding the energy absorption capacity of the frame during each cycle considered in this experiment, the hybrid fibre reinforced concrete beam will give maximum energy absorption when compare to other conventional beam. The comparison of energy absorption for various beams are shown in fig




MODE OF FAILURE

As the load increases, the number of cracks or crack width increases for each beam. The presence of fibre inside the beam will resist the crack development by forming a bridging across the crack.ie the fibres act as crack arresting material. The pictorial representation for the mode of failure for each beam is shown in


Comparison of Hooked End & Crimpled Fibre RC Beam with Conventional RC Beam


Comparison of Hybrid Fibre RC Beam with Conventional RC Beam

## CONCLUSION

### *7.1 GENERAL*

The experimental investigation is carried out to study the behaviour of High Performance Fibre Reinforced Concrete Beam, such as Hooked end, Crimpled, Hybrid fibre reinforced concrete beam and Conventional high performance reinforced concrete beam, subjected to cyclic loading. The test results are compared with that of the Conventional high performance reinforced concrete beam.

It based on study parameters such as first crack load, ultimate load, cumulative ductility factor and energy absorption, we compare all the beams with that of conventional concrete beam. The following observation has been inferred from the experimental programme.

- The ultimate load for the hybrid fibre reinforced concrete beam was 1.45 times greater than that of conventional RC beam
- The first crack load for the hybrid fibre reinforced concrete beam was 1.5 times greater than conventional RC beam
- The ultimate load for hybrid, crimpled and hooked end beams are about 43.33%, 36.6% and 20% respectively more than that of conventional RC beam
- The first crack load for hybrid, crimpled and hooked end beams are about 50%, 12.5% and 25% respectively more than that of conventional beam.
- The ductility value of hybrid fibre RC beam is about 5.18 times than that of conventional RC beam and 2.48 times than that of hooked end RC beams.

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- The energy absorption of hybrid fibre RC beam is about 2.38 times than that of conventional RC beam and 1.53 times than that of crimpled RC beams.
- In general the presence of steel fibres increases both ductility and energy absorption capacity which is required for earthquake poof zones.
- Moreover the presence of hybrid fibre results in higher load carrying capacity apart from enhanced ductility and energy absorption.

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