



Article Title: Shear Behaviour of RCC Beams Retrofitted with Ultra High Performance Concrete

Shear Behaviour of RCC Beams Retrofitted with Ultra High Performance Concrete

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ABSTRACT

The main contributing factors are change in their use new design standards, deterioration due to corrosion in the steel caused by exposure to an aggressive environment and accident events such as earthquakes. In such circumstances there are only two possible solutions: replacement or retrofitting. Full structure replacement might have determinate disadvantages such as high costs for material and labour, a stronger environmental impact and inconvenience due to interruption of the function of the structure. Whenever possible, it is often better to repair or upgrade the structure by retrofitting or strengthening. In this study, shear behaviour of reinforced concrete beams retrofitted with Ultra High Performance Fibre Reinforced Concrete (UHPFRC) with two types of fibres (crimped and micro steel fibre) and a plain UHPC were compared with control beams. A normal M20 mix was designed for the study. Two point loading system was adopted for the test. And deflection were noted for each load increment. Behaviour of retrofitted beams and control beams were studied by comparing the properties such as first crack load, ultimate load and load deflection plot. The result showed that shear performance was improved by 88% for UHPFRC-C, 78% for UHPFRC-M and 36% for UHPC, showing the effect of fibres which improved the shear performance of UHPFRC retrofitted beams.

Keywords: Retrofitting of RC beams, Ultra high performance concrete, shear performance.

1 Introduction

Existing concrete structures may, for a variety of reasons, be found to perform unsatisfactorily. This could manifest itself by poor performance under service loading, in the form of excessive deflections and cracking, or there could be inadequate ultimate strength. Additionally, revisions in structural design and loading codes may render many structures previously thought to be satisfactory, noncompliant with current provisions. In the present economic climate, rehabilitation of damaged concrete structures to meet the more stringent limits on serviceability and ultimate strength of the current codes, and strengthening of existing concrete structures to carry higher permissible loads, seem to be a more attractive alternative to demolishing and rebuilding. Various repair procedures are resin injection, stitching, bonding of external reinforcement, routing and sealing, drilling and plugging, chemical grouting, flexible sealing and Portland cement grouting. The techniques used for carrying out repair of damaged



Article Title: Shear Behaviour of RCC Beams Retrofitted with Ultra High Performance Concrete

structures vary from one structure to the other, depending on the type of distress. Depending on the location and environmental conditions, suitable materials should be chosen for retrofitting, from the point of view of long term performance of the structures after repair. Retrofitting schemes are based on the cost and availability of the materials.

The different methodologies include patch repair, jacketing technique using concrete or steel, fibre reinforced polymer (FRP) wrapping, attaching steel plates externally to structural elements by epoxy bonding or bolting, fibre concreting and external pre stressing [1]. But one thing that should keep in mind before adopting a technique is its overall performance in their service life, it should provide adequate strength, durable, and economic. Certain inventions are being conducting to improve the process of retrofitting efficiently. Ultra High Performance Concrete is one of them which is defined by its high strength and durability. It was developed in Europe in the 1980s for specialized applications that demand superior strength and corrosion resistance for marine anchors, piers and seismic structures [2].

This concrete consist of a combination of Portland Cement, fine sand, silica fume, high-range water-reducing admixture (HRWR), fibres (usually steel), and water. The term Ultra High Performance Fibre Reinforced Concrete (UHPFRC) is a cement mixture with very low water-cement ratio characterized by the presence of very fine quartz sand instead of ordinary coarse aggregate. The absence of coarse aggregate was considered by the inventors to be a key aspect for the microstructure and the performance of the UHPFRC in order to reduce heterogeneity between the cement matrix and the aggregate. However, due to the use of very fine sand instead of ordinary aggregate, the cement density of UHPFRC is high [3]. Petr et al. (2013) [4] investigated the mechanical properties of UHPFRC with a compressive strength exceeding 150 MPa he conducted compressive strength test, bending strength, direct tensile strength, fracture energy and modulus of elasticity of concrete to study the mechanical properties of UHPFRC he also made a comparison of properties of UHPFRC with high performance concrete, fibre reinforced concrete and normal concrete. The results showed excellent performance of UHPFRC in all categories. The fracture energy of UHPFRC was obtained five times higher than that of conventional fibre reinforced concrete. Then it was Prem et al. (2012) he studied different mixing methodologies and curing procedures such as normal curing, hot air curing and steam curing for the development of UHPFRC. The cube and cylinder strength observed for different mixes were recorded, which were in the range of (180 - 132) MPa and (171 - 193) MPa respectively. The flexural and split tensile strength showed a linear relationship and reinforcement index. From the results obtained it was recommended that fibres with higher aspect ratio yields better flexural and tensile strength.

The results reflect that even after cracking the residual capacity is very high for both long fibres and short fibres. Durability testing were also conducted and the results shown that water absorption and sorptivity clearly shows that it has very high corrosion resistance, low water absorption and good sorptivity to make it usable in all types of aggressive environments [3]. Later he also studied the flexural behaviour of damaged RCC beams strengthened with Ultra



Article Title: Shear Behaviour of RCC Beams Retrofitted with Ultra High Performance Concrete

High Performance Fibre Reinforced Concrete overlay. Control RCC beams of size 100 x 200 x 1500 mm with M30 grade of concrete are tested up to failure. Damage is introduced by preloading the RC beams up to 80 and 90% of the failure load of control RCC beam. UHPC overlay is added on the tension face of the beam with epoxy and tests are conducted for flexural behaviour. It was observed that there is significant increase in load carrying capacity and ductility in the case of preloaded RC beams strengthened with UHPC overlay [5].

Hannawi et al.(2016) [6] investigated the effect of adding different type of fibres on the microstructure and the mechanical behaviour of cementitious composites UHPFRC. Mainly steel, mineral and synthetic fibres of different dimensions (microscopic & macroscopic) were used in the study. The microstructure of the specimens was examined by using SEM observation and by measuring the porosity, intrinsic permeability and P-wave velocity. The mechanical behaviour under loading has been studied using a uni-axial compression and the results showed that the fibre has a relatively slight influence on the compressive strength and elastic modulus of concrete except for steel fibre which improves the strength because of its intrinsic rigidity. The fibres clearly restrain the cracking process in concrete under mechanic loading. Studies proved that the UHPFRC got improved mechanical as well as durability properties and thus it can be considered as a retrofitting technique. So this study focused towards the development of a retrofitting system using the addition of a thin overlay of Ultra High Performance Fibre Reinforced Concrete (UHPFRC) to reinforced concrete (RC) members of M20 grade which was made deficient in shear capacity and the performance of the retrofitted beams were taken for the study.

2 Recent Work

The experimental work consisted of casting and testing of beams of length 1000 mm and cross section 100 mm x 150 mm. The reinforcement details are shown in Figure1. Two 10 mm diameter bars were used as tension reinforcement; two 8 mm bars were used as compression reinforcement 2 legged 6 mm stirrups were used at a spacing of 90 mm center to center were provided at flexural span and at two ends of the shear member to induce shear failure. Strain gauges were provided on one of the two bars of each diameter. The rebars were levelled smooth on the portion where strain gauge was to be attached and then is attached using suitable adhesive. The lead wires were then soldered to the stain gauge and proper insulation were provided in order to avoid damaging of the gauge. The strain readings were measured using strain indicator and for measuring the central deflection dial gauges were used. Testing of beams were carries out using an Universal testing machine of 1000kN capacity and delection, strain readings and crack propogation were measured at each 2.2kN increment of loading



Article Title: Shear Behaviour of RCC Beams Retrofitted with Ultra High Performance Concrete

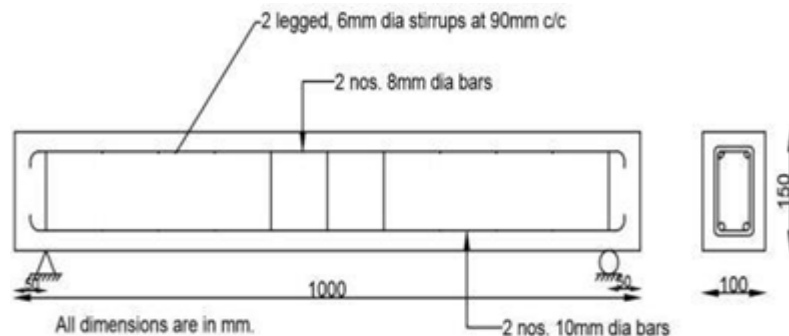


Figure 1: Reinforcement detailing for shear beam [2]

2.1 Materials Used

Ordinary Portland cement (53 grade) conforming to IS: 12269-1987 (reaffirmed 2004) [16], 75% of fine aggregate passing through 600 μ m and retained on 300 μ m, 25% of fine aggregate passing through 300 μ m and retained on 150 μ m, silica fume, glass powder and super plasticizer were used for the investigation. The basic philosophy lies in complete elimination of coarse aggregate to impart greater homogeneity, with mineral and chemical admixture to get stronger gel formation during hydration. Two types of fibres were used in the study both of same aspect ratio 60 (crimped steel fibre 30mm length and 0.5mm diameter and micro steel fibre 6mm length and 0.1mm diameter). The mix proportion was selected from the optimum mix obtained from the trial mixes conducted in previous study. The mechanical properties were also determined for finding the optimum mixes.

1. Micro steel fibres
2. Crimped steel fibres

Table 1: Properties of fibres

Type of fibre	Crimped steel fibre	Micro steel fibre
Length (mm)	30	6
Diameter (mm)	0.5	0.1
Aspect ratio	60	60

Table 2: Mix proportion of M20 and UHPC mix

Mix	Cement (kg/m ³)	Fine aggregate (kg/m ³)	Coarse aggregate (kg/m ³)	Silica fume (kg/m ³)	Glass powder (kg/m ³)	Super plasticizer (L/m ³)	Water (L/m ³)	Compressive strength (MPa)
UHPC	712	733	-	178	178	24	144	153
M20	340	666.4	1326	-	-	-	153	28.50



Article Title: Shear Behaviour of RCC Beams Retrofitted with Ultra High Performance Concrete

Table 3: Mix proportion of UHPFRC Mixes

Mix	Cement	Fine Aggregate Kg/m ³	Silica Fume	Glass powder	Super plasticizer L/ m ³	Water	Steel fibre	
							micro	crimped
							Percentage volume	
UHPC	712	733	178	178	24	144	0	0
UHPFRC-C0.25	712	733	178	178	24	144	0	0.25
UHPFRC-C0.5	712	733	178	178	24	144	0	0.50
UHPFRC-C0.75	712	733	178	178	24	144	0	0.75
UHPFRC-C1.00	712	733	178	178	24	144	0	1.00
UHPFRC-C1.25	712	733	178	178	24	144	0	1.25
UHPFRC-C1.5	712	733	178	178	24	144	0	1.5
UHPFRC-M0.25	712	733	178	178	24	144	0.25	0
UHPFRC-M0.5	712	733	178	178	24	144	0.5	0
UHPFRC-M0.75	712	733	178	178	24	144	0.75	0
UHPFRC-M1.00	712	733	178	178	24	144	1.00	0
UHPFRC-M1.25	712	733	178	178	24	144	1.25	0
UHPFRC-M1.5	712	733	178	178	24	144	1.5	0

Optimum fibre content was found out and retrofitting was carried out only with the optimum mixes.

2.2 Preparation of specimens

Total of 12 beam specimens were prepared with M20 grade concrete. The specimens were prepared and cured for 28 days. After 28 days, the control specimens were tested and then preloading was done. The reinforcement provided on beams was given in Figure 2.

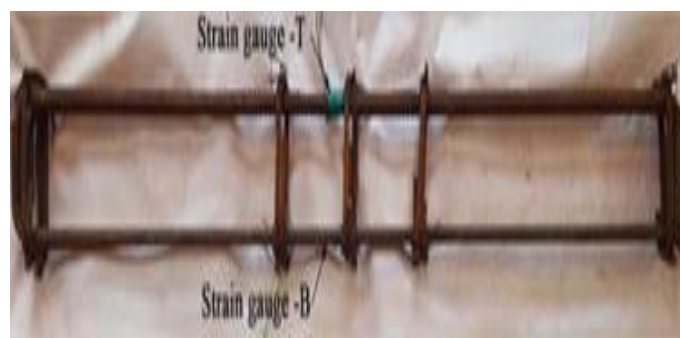


Figure 2: Reinforcement provided on beams



Article Title: Shear Behaviour of RCC Beams Retrofitted with Ultra High Performance Concrete

Table 4: Specimen detail

Specimen ID	Size	No. of specimens
CB	100mm x 150mm x 1000mm	3
UHPC		3
UHPFRC-C		3
UHPFRC-M		3

3 Proposed work Explanation

The beams were tested under two point loading. The values obtained from the dial gauge at the mid span were used to plot the load deflection curve. Strain gauges were used to measure the strains. These strain values were used for plotting the moment curvature relationship. The moment was obtained from the loading configuration. The loading configuration for two points loading is shown in Figure 4

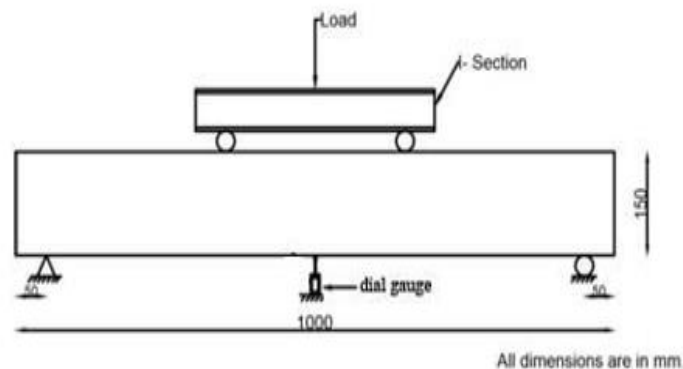


Figure 3: Loading configuration

3.1 Distressing of beam specimen

The three control beams (CB) were loaded up to failure and their ultimate loads were determined. The remaining nine beams were then distressed up to 67% of the ultimate load.

3.2 Retrofitting of Pre-Loaded Beams

The preloaded beams are then U- wrapped with UHPC and UHPFRC's, 2.5cm was adopted as overlay thickness and was done over the full span. Retrofitting was made easily with the help of moulds and they were demoulded and kept for curing. Procedure adopted for retrofitting was given in Figure 4



Article Title: Shear Behaviour of RCC Beams Retrofitted with Ultra High Performance Concrete

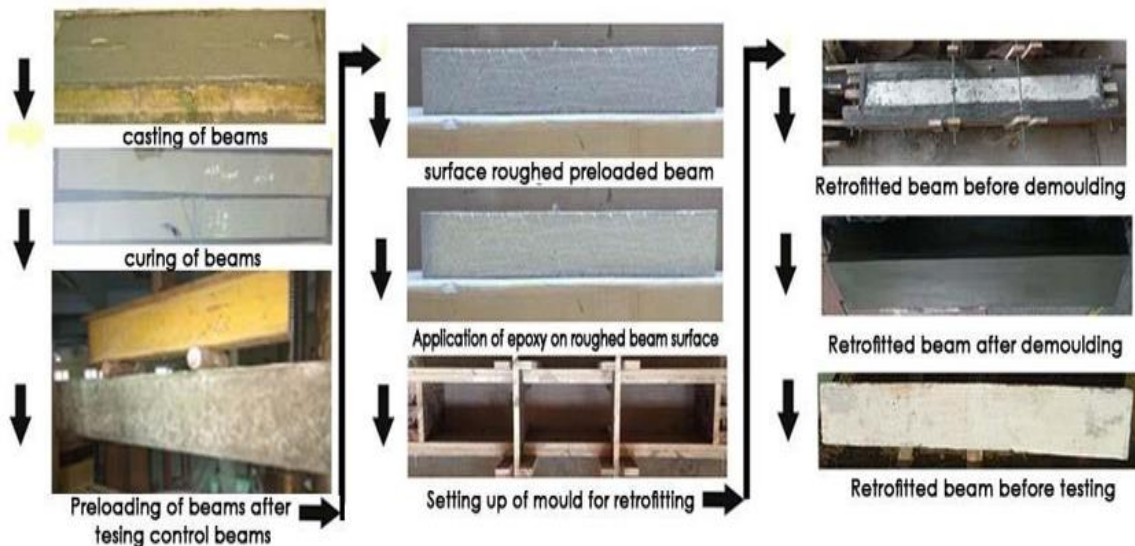


Figure 4: Retrofitting procedure

3.3 Shear Test on Retrofitted Beams

After the completion of curing period, the beams were then tested in the universal testing machine with the same test procedure as mentioned earlier. The beams that were prepared shear deficient and hence the shear behaviour of these beams was studied. The beams were tested in a 1000 kN Universal Testing Machine. The flexure and shear behaviour of the UHPC retrofitted and UHPFRC's retrofitted beams were compared to that of the control beams. Figure 7 shows the test setup used for the study.



Figure 5: Test setup

4 Results and Discussion

4.1 Compressive strength and slump values of UHPC and UHPFRC mixes

Compressive strength and slump values of trial mixes were given in Table 5 and from the results optimum fibre content for crimped steel were found out as 1.00 % and that for micro



Article Title: Shear Behaviour of RCC Beams Retrofitted with Ultra High Performance Concrete

steel were found out as 1.25%. Tests were conducted based on ASTM code.

Table 5: Compressive strength and slump values of UHPC and UHPFRC mixes

Mix designation	Compressive strength (N/mm ²)	Slump(mm)
UHPC	151	247
UHPFRC-C0.25	153	243
UHPFRC-C0.5	155	238
UHPFRC-C0.75	157	234
UHPFRC-C1.00	158	230
UHPFRC-C1.25	145	218
UHPFRC-C1.5	132	198
UHPFRC-M0.25	153	246
UHPFRC-M0.5	155	241
UHPFRC-M0.75	158	237
UHPFRC-M1.00	160	234
UHPFRC-M1.25	163	231
UHPFRC-M1.50	153	221

4.2 Hardened properties of UHPC and UHPFRC mixes

Some of the hardened properties were also studied and the results were given in Table 6. All the tests were done according to ASTM and BS codes.

Table 6: Hardened properties of UHPC and UHPFRC mixes

Mix Designation	Compressive strength (N/mm ²) ASTM C 109[21]	Modulus of rupture (N/mm ²) ASTM C 1609[22]	Modulus of elasticity (N/mm ²) ASTM C 469[23]	Split tensile strength (N/mm ²) BS 1881:1983[24]
UHPC	151	18.2	4.04x10 ⁴	12.8
UHPFRC-C1.00	158	33.6	4.71x10 ⁴	20.1
UHPFRC-M1.25	163	31.5	4.48x10 ⁴	18.6

From the results it was clear that the addition of steel fibre had improved the mechanical properties of the mix

4.3 Crack Pattern and Failure

The crack pattern for all the retrofitted and normal beams were shown in Figure 8. Cracks were not observed at the beginning of the test. After some time, shear cracks initiated at shear zone. As the load increased, the existing cracks started to propagate and new cracks were also developed.



Article Title: Shear Behaviour of RCC Beams Retrofitted with Ultra High Performance Concrete



Figure 6: Crack pattern

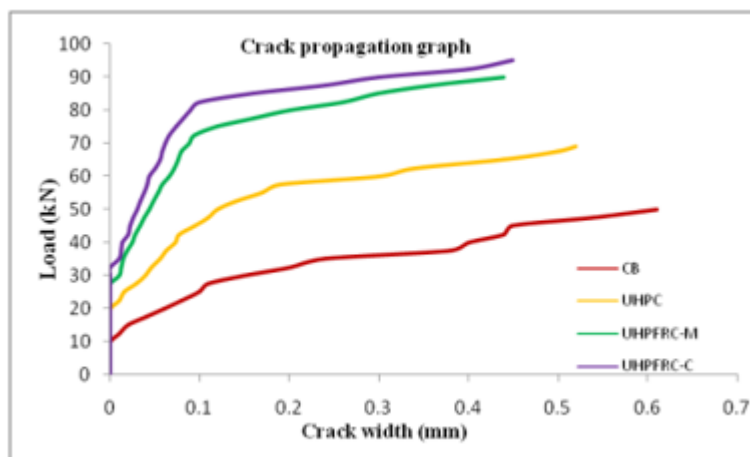


Figure 7: Crack propagation graph

At the ultimate stage most of the cracks travelled up to the top of the beam, even though the number and size of the cracks were different in normal and retrofitted beam. In retrofitted beam all the cracks were shear type. In the control specimen comparatively wider cracks were noticed at shear region. During testing, the crack width was measured using crack detection microscope of 50x magnification at load increment of 2.5 kN. Crack propagation graph of all the retrofitted and normal beams was given in Figure 9. The crack width pattern was different in normal and retrofitted beam. The maximum crack width value was observed in normal beam which was 0.64 mm.

4.4 Load- Deflection Behaviour at Mid Span

The load and deflection values recorded during the two point loading test of beams were used to draw the load deflection graphs. Figure 10 shows the load- deflection plot of the control beam specimen and retrofitted specimens. From the load deflection plot of shear beams, it was observed that initially the curve was linear up to certain load for the control as well as for the retrofitted specimens. For the CB, it was observed that the linearity was up to the first crack load. Further application of load causes the curve to deviate from linearity. In case of the



Article Title: Shear Behaviour of RCC Beams Retrofitted with Ultra High Performance Concrete

retrofitted beams, the load carrying capacity was increased than the CB. The steel fibres in UHPFRC's arrested the micro cracks developed thus improved the load carrying capacity than UHPC. Due to the presence of long steel fibres in UHPFRC-C, the load carrying capacity is much improved when compared to UHPFRC-M since the fibres are of short in length. Also the initial, yield and ultimate load were given in Table 7. Energy absorption was also found by calculating the area under the load deflection plot. Due to the limitations in the experimental set up, the load deflection graph could be plotted only up to 80 % of the peak load, in the descending portion of the curve. Thus, the energy absorption was calculated as the area under the curve up to the peak load and under the descending portion up to 80 % of the peak load. The energy absorption of beams is shown in Table 8.

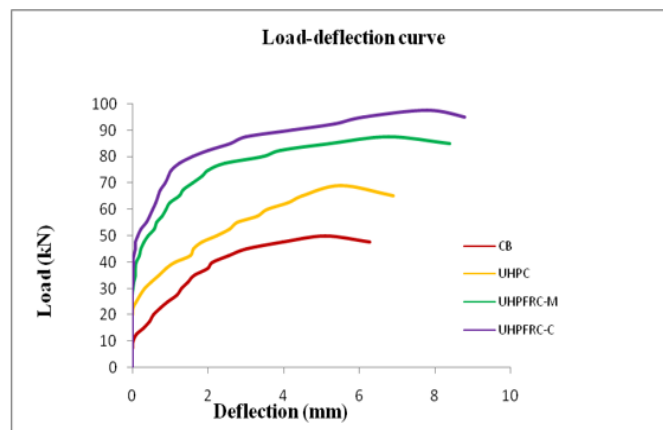


Figure 8: Load-deflection plot for shear retrofitted beams

Table 7: Initial, yield and ultimate load values

Beam ID	Initial Crack load (kN)	Yield load (kN)	Ultimate Load (kN)	
			Absolute	Relative
CB	13	41	50	1
UHPC	23	56	68	1.38
UHPFRC-M	30	74	89	1.78
UHPFRC-C	35	79	94	1.88

Table 8: Energy absorption

Specimen	Energy absorption (kNmm)
CB	289.25
UHPC	370.88
UHPFRC M	631.82
UHPFRC C	718.23



Article Title: Shear Behaviour of RCC Beams Retrofitted with Ultra High Performance Concrete

4.5 Moment curvature Relationship

Moment curvature plot for the control and retrofitted beams were given in Figure 11. The moment curvature can be said to have three stages.

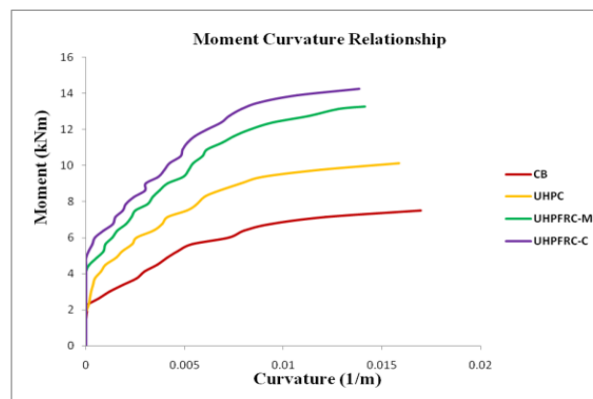


Figure 9: Moment curvature relationship

First stage is till initial cracking, second stage till yielding of tension steel and the third stage to limit of useful strain in concrete. The curve is linear up to first crack moment. Further when the moment increases, the curve shifts from linearity. When the moment reaches yield moment, the curves become flat. When steel yields, a large increase in curvature occurs with a small change in moment.

4.6 Ductility indices

Displacement ductility was calculated as the ratio between the displacements at ultimate load to the displacement at yield load. The ductility could be considered at 80% of the peak load, because this takes into account, the softening part of load deflection curve. Hence for calculating ultimate deflection, 80% of peak load is considered. Softening ductility consideration is important in seismic design and where large deformations are involved. Failure of an under reinforced beam is called tension failure.

Table 9: Ductility indices of the beams

Beam ID	Displacement Ductility		Curvature Ductility	
	Absolute	Relative	Absolute	Relative
CB	2.11	1	2.07	1
UHPC	2.26	1.07	2.19	1.05
UHPFRC-M	3.12	1.47	2.33	1.12
UHPFRC-C	3.2	1.51	2.45	1.18

This is because the primary reason of failure is the yielding of steel bars. The large increase in



Article Title: Shear Behaviour of RCC Beams Retrofitted with Ultra High Performance Concrete

curvature, before collapse of the beam is an indication of ductile failure of beam. Curvature ductility was calculated as the ratio of curvature at ultimate load to that of curvature at yield load. The ductility index of the beams is shown in Table 9.

4.7 Shear behaviour of beams

Behaviour of retrofitted elements under shear was evaluated by calculating the maximum shear force at the supports and the results were shown in Table 10. The results showed that the shear carrying capacity of all the retrofitted specimens when compared to the control specimens.

Table 10: *Shear behaviour of beams*

Beam ID	Ultimate shear force(kN)
	Absolute
CB	25
UHPC	34
UHPFRC-M	44.5
UHPFRC-C	47

Results showed that the ultimate shear capacity got improved by the addition of fibers, for UHPFRC-M it got improved by 88% for UHPFRC-C, 78% for UHPFRC-M and 36 % for UHPC when compared to the control specimens.

5 Conclusions

From the experimental investigation conducted, the load deflection behaviour, crack width, energy absorption, ultimate load carrying capacity, moment curvature relationship and ductility indices mixes were studied and based on the results obtained, the following conclusions were made:

- Both UHPFRC-M and UHPFRC-C shown good crack arresting capacity compared to beams retrofitted with UHPC
- The ultimate capacity was improved by 88% for UHPFRC-C, 78% for UHPFRC-M and 36 % for UHPC, showing the effect of fibres which improved the shear performance of UHPFRC retrofitted beams.
- The energy absorption capacity was increased by 148% for UHPFRC-C retrofitted beam and 118 % for UHPFRC-M, but for beams retrofitted with UHPC, an increase of 28% was only observed.

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