BEHAVIOR OF HIGH PERFORMANCE FIBRE REINFORCED CONCRETE COMPOSITE BEAMS IN FLEXURE

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In this study, the experimental investigation on the flexural test of bagasse ash blended high performance concrete (HPC) and influence of steel fibre (STF) and polypropylene fibre (PPF) are carried out. The flexural test was done for beam size of 150 mm x 200mm x 1800mm with two point loading system. The concrete was considered for M60 grade (P series) as recommended by P.C.Aitcin. The blend mix included both free STF (Q series) and PPF (R series), and furthermore the hybridization of STF and PPF (S series) at a total volume fraction of 1.0% by volume of concrete with 10% bagasse ash as a substitution of cement. Structural behavior of eleven bagasse ash blended high performance concrete beams reinforced with steel, polypropylene and hybrid fibres were examined. The behavior of each beam was assessed with respect to initial crack, ultimate load, ultimate deflection, flexural strength, ductility and toughness. The inclusion of fibres increased the failure load and ensured the ductile behavior of the beams. The results demonstrated that adding hybrid fibres enhanced the mechanical properties as well as the structural behavior of beams

Keywords: *bagasse ash, high Performance concrete, steel fibres, polypropylene fibres*

1. Introduction

Materials with enhanced properties, specifically, strength, workability, toughness, ductility and durability are called as high performance materials. In perspective of the performance criteria, an endeavor was made with Bagasse Ash (BA), a dynamic pozzolan due to its surface region with significant measure of silica and consideration of fibres[1,2]. Porosity of the concrete can be reduced by inclusion of bagasse ash in concrete, whereas it acts as micro filler in concrete [3]. At the point when fibres are added to the concrete, it turns out to be more ductile and upgrades the control against crack growth in longitudinal direction. Hybrid fibre-reinforced concretes, which are reinforced with two or more different types of carefully, selected fibres to provide superior properties [4].The workability of high performance fibre reinforced concrete composites decreases with increase in the fibre content. Addition of polypropylene fibres in concrete shows better workability than the steel fibres. Inclusion of 10% bagasse ash enhances the workability and strength properties of concrete, which acts as micro filler and increases the density of cement paste. The fibres are more effective in high performance concrete, due to the effective bond between the fibres and matrix of concrete. The hybrid fibre has an influential effect on the strength properties of high performance concrete. It demonstrates the better ductile performance compared to the plain concrete [5]. As cracks happen at different stages and sizes in concrete, the utilization of different fibres with different lengths is an effective method to solve this issue [6]. In a well structured composite system, there is a beneficial interaction among the fibres, which brings about a superior performance of the hybrid system than that of the mono fibre composite. The main purpose of the combination of different types of fibres is to control cracks at different zones of the cementitious material, at various size levels and during different loading stages [7].The investigations on the behavior of light weight concrete beams with and without steel fibres reveals that the addition of about 30kg/m^3 of hooked end steel fibre leads to an increase of about 20% of ultimate load, and ductility increases to about 65% [8].Incorporation of steel and polypropylene fibres enhanced the mechanical properties of high strength concrete. The addition of 1% steel fibre significantly enhances the splitting tensile strength and flexural strength of concrete. The hybrid mix contained 0.85% steel and 0.15% polypropylene fibre demonstrated better outcomes among hybridization.The final collapse load takes longer than plain concrete beams when steel and polypropylene fibres were included. In the meantime, more fibre content in concrete diminishes the deflection rate of total deflection [9].Fuse of steel fibres up to 1.5% volume fraction in high performance concrete results in significant improvement on indirect tensile strength [10].

The experimental work carried out in this study is on the behavior of reinforced beam under flexure. Based on the experimental results on eleven beam specimens, comparison of control beam specimen and 10% bagasse ash blended beam specimen (P series), steel (Q series) and polypropylene reinforced beam specimens(R series) and hybrid fibre reinforced concrete beam

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specimens(S series) were carried out. The primary objectives of this study are to investigate the suitable percentage of fibres with 10% bagasse ash which gives more load carrying capacity, flexural strength, flexural toughness and ductility factor.

2. Research Significance

Limited investigation has been carried out on performance evaluation of bagasse ash as a supplementary cementitious material in reinforced concrete elements, which motivates the authors to study the performance of scaled model of beam specimen in flexure. Better performance was observed in literature on behavior of high performance fibre reinforced concrete composites compared to fibre reinforced concrete. Preliminary investigations were carried out by authors on the strength properties of high performance concrete with various percentages (5%, 10%, 15% and 20%) of bagasse ash as partial replacement of cement. The test results indicate that the incorporation of Bagasse ash up to 10% provides improved properties of hardened concrete. Hence, composites are prepared using constant 10% of bagasse ash in weight of cement for all beam specimens. Mechanical and workability properties of 10% bagasse ash blended high performance fibre reinforced concrete gives better performance compared to conventional concrete [5]. Very few studies are conducted on the behavior of high performance reinforced concrete composite beam in flexure with steel and polypropylene fibres. The proportions of steel and polypropylene fibres differ with 0.25%, 0.5% and 0.75%, 0.15%, 0.3% and 0.45%. To study the effect of hybridization of fibres, the mix of both fibres were made with a fraction of 1% by volume of concrete. Experimentally detailed investigations were conducted to study the behavior of beam with various high performance fibre reinforced concrete composites. The volume fractions of fibres used in this investigation are taken from the maximum suggested literature.

3. Experimental research work

3.1. Materials

3.1.1. Cement & Bagasse ash

53 grade ordinary Portland cement was used for making high performance concrete specimens. The bagasse ash used in the test was obtained from Gobichettipalayam, TN, India. Bagasse ash varied at constant 10% by weight ofcement. The used cement and bagasse ash have specific gravity of 3.15 and 2.18. Initialand final setting time of ordinary Portland cement were found to be 80 min and 150 min with 29.5 % standard consistency, whereas 10 % bagasse ash blended cement has initial and final setting time of 230 min and 320 min with 33.5% standard consistency. The chemical composition, Loss on ignition of both OPC and BA are shown in Table 1, indicating the BA has almost 5 times better silica content than that of OPC and consists of rational quantity of CaO and Al_2O_3. In addition, BA showed an LOI value of 5.4%. The Energy Disperse X-ray (EDX) spectrum of BA also clearly indicates the peak value of SiO_2 content (55.49%) as shown in Table 1.

3.1.2. Aggregate

Local coarse aggregate in surface dry condition of size confirming to 20mm were used. River sand was used as fine aggregate in saturated surface dry condition. Coarse aggregate and fine aggregate specific gravity was found to be 2.88 and 2.71. Water absorption of coarse aggregate and fine aggregate was 0.5% and 1.02% respectively. All the aggregates were conforming to IS 383: 1970 [11] specifications.

3.1.3. Fibres

In this study, hooked end steel fibres with length of 60 mm, diameter of 0.75 and aspect ratio of 80, and polypropylene fibres with length of 12 mm, diameter of 0.022 and aspect ratio of 545 were employed. The tensile strength of the steel fibre and polypropylene was 1050 MPa and 350 MPa. Steel fibre content varies as 0.25%, 0.50% and 0.75%, whereas polypropylene fibre content varies as 0.15%, 0.30% and 0.45%. The combination of both steel and polypropylene as a hybrid fibre varies as 0.85 STF and 0.15 PPF, 0.70 STF and 0.30 PPF, 0.55 STF and 0.45 PPF as fraction of 1 % by volume of concrete. The shape and dimensions of fibres are shown in Figure.1.

3*.1.4. Super plasticizers*

The properties of super plasticizer were given as Polycarboxlic ether based super plasticizer, Colour – Light brown, Specific Gravity – 1.08 ± 0.01 at 25°C, pH ≥ 6. The dosage of super plasticiser is adopted is 10 lit/m^3 of concrete. It was primarily developed for application in High Performance Concrete for reducing water content.

3.2. Preparation of Mixtures

M60 grade mix design was done as per the method proposed by P.C.Aitcin [12], a simple approach that follows ACI 211-1 standard practice. The mix proportions for all the specimens are categorized in Table 2. Cement content is 483 kg/m^3 for the control specimen and 10% of cement is replaced by bagasse ash for the remaining

Table 1

Chemical composition of cement and bagasse ash (%)

Parameter	SiO_2	Al_2O_3	Fe_2O_3	MgO	Na_2O	K_2O	CaO	LOI
Cement	11.99	2.64	4.03	0.85	0.54	1.52	70.93	0.8
Bagasse ash	55.49	9.92	8.29	7.96	0.93	8.34	8.74	5.4

Fig.1 - Shape and dimensions of (a) Steel fibre (b) Polypropylene fibre.

Table 2

Mix Proportion

Specimen No.	Designation	Water	Cement	BagasseAsh	Fine Agg.	Coarse Agg.	Fibre Volume Fractions %	
		(kg/m³)					STF	PPF
P1	Plain	127.8	483	-	823	1042	-	-
P2	BA10	127.8	433	50	823	1042	-	-
Q1	STF0.25	127.8	433	50	823	1042	0.25	-
Q2	STF0.50	127.8	433	50	823	1042	0.5	-
Q3	STF0.75	127.8	433	50	823	1042	0.75	-
R1	PPF0.15	127.8	433	50	823	1042	-	0.15
R2	PPF0.30	127.8	433	50	823	1042	-	0.3
R3	PPF0.45	127.8	433	50	823	1042	-	0.45
S1	PPF0.15STF0.85	127.8	433	50	823	1042	0.85	0.15
S2	PPF0.30STF0.70	127.8	433	50	823	1042	0.7	0.3
S3	PPF0.45STF0.55	127.8	433	50	823	1042	0.55	0.45

mixes. The weight of fine aggregate and coarse aggregate are 823 kg/m^3 and 1042 kg/m^3 respectively. The water content of the mix and W/B ratio are 127.8 kg/m^3 and 0.29. The dosage of the super plasticizer was adopted as 10 lit/m^3 of concrete. The steps involved in mix procedure for bagasse ash Blended Fibre reinforced high performance concrete are: (i) Coarse aggregate and fine aggregate were mixed in a concrete mixer initially; (ii) Cement, bagasse ash and fibres were spread and mixed in dry state; (iii) Later, water was added and mixed thoroughly and (iv) Finally, the freshly mixed bagasse ash blended fibre reinforced concrete was cast into moulds and vibrated to eliminate entrapped air. Specimens were allowed to stand dry for 24 h after casting. Later on, specimens were demoulded and placed in water till the age of testing.

3.3. Testing of specimens

The flexural beam test specimens were designed as under reinforced section and consisted of 3 numbers of 16mm diameter bars in tension and 2 numbers of 12mm diameter bars in compression. 2 legged stirrups of 8mm diameter at a spacing of 100mm provided throughout the section. The reinforcement detail of beams tested for flexure is shown in Figure.2. A total of 10 high performance concrete beams specimens of size 150 mm x 200mm x 1800mm were casted for w/b ratio 0.29 with 10 % bagasse ash as mineral admixture and fibres (steel and polypropylene). One beam without admixtures and fibres was kept as control beam. Test setup for beams under flexural behavior is shown in Figure. 3.The beam specimens were cast and curing was done for 28 days. After curing, the specimens were kept dry for

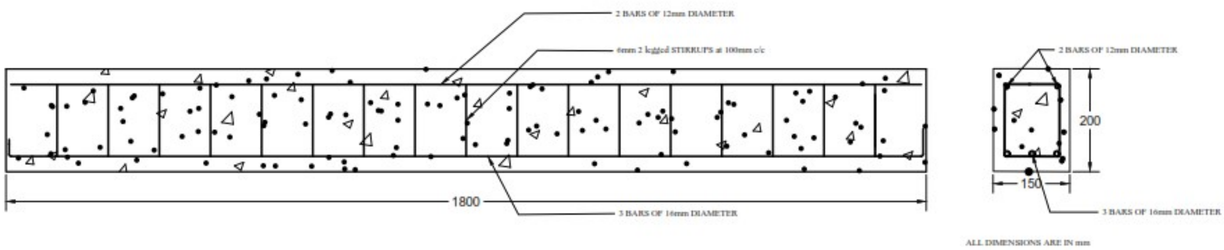

Fig..2 - Reinforcement details of beam specimen.

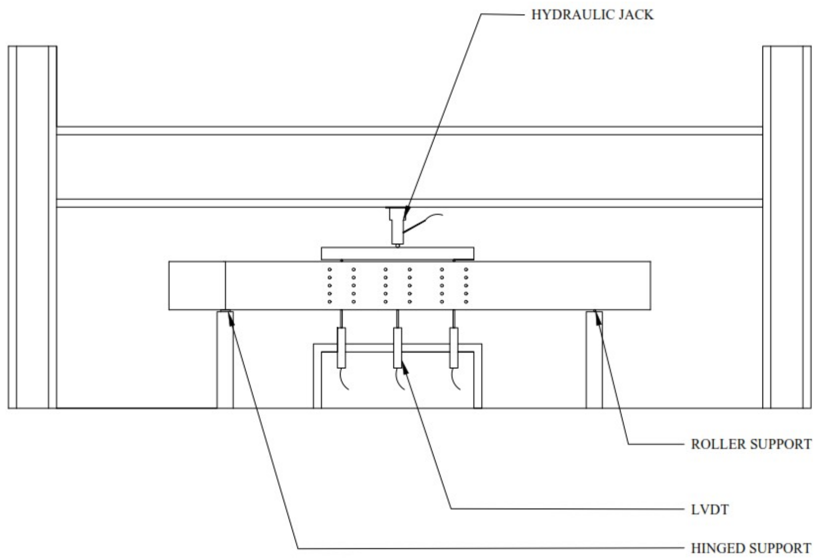

Fig. 3 Test set up of beam.

Table 3

Beam specimen results tested for flexure

Description	Specimen No.	Initial Crack load (kN)	Ultimate load (kN)	Ultimate Displacement Δ_u (mm)	Theoretical Ultimate Load (kN)	Experimental Ultimate Load (kN)	Ratio (Exp/The)	Average of (Exp/The) ratio
P- HPC and HPC with %10 BA	P1	44	176	22.54	96.3	176	1.83	
	P2	50	182	24.80		182	1.89	
Q- HPC withSteel fibre (STF)	Q1	54	199	26.10		199	2.07	2.1
	Q2	62	203	25.40		203	2.1	
	Q3	68	205	26.72		205	2.13	
R- HPC withPolypropylene fibre (PPF)	R1	48	184	23.50		184	1.91	1.94
	R2	54	186	26.90		186	1.94	
	R3	58	189	26.00		189	1.96	
S- HPC withHybrid fibre	S1	76	218	29.40		218	2.26	2.22
	S2	70	215	29.10		215	2.23	
	S3	62	211	29.00		211	2.19	

24 hours. The centre line and loading point lines are marked on the specimen before testing. The loading pattern is two points loading system. The loading points are 200mm from the centre on the either side. The point load is applied through a hydraulic jack. The loading rate is 2 KN. The LVDT instruments are placed at the centre and loading points on either side exactly at the bottom face of the beam. The strain gauges are placed at 600mm from the centre towards left and 400mm towards right side of the beam. For every 2KN the strains and deflections readings are taken down. The first flexure crack is marked and the corresponding load is noted. The loading is done until the beam fails due to yielding of steel.

4. Results and Discussion

4.1. Behavior of beams in flexure

The test results for the beam specimens cast with 0.29 w/b ratio and tested for flexure behavior at the age of 28 days are presented in Table 3. The Q3 specimen after testing with crack pattern is shown in Figure.4. P2 specimen beam resulted in higher ultimate loads compared to P1 specimen. Similarly higher deflection was observed in P2 specimen than the P1 specimen. The failure in specimen was due to concrete spalling and yielding of deformed steel. The comparison between the theoretical ultimate load and experimental loads were determined and tabulated in Table 3. The initial crack load values of P2 specimen increased when compared to that of P1 specimen. Recorded value indicates that addition of BA increased the flexural strength of the beams as it delays the first crack is illustrated in Figure.7. The beam specimen Q3 had the ultimate load carrying capacity of 205 kN in flexure. This is 16.47% higher than the load carrying capacity of P1 specimen and 12.63%

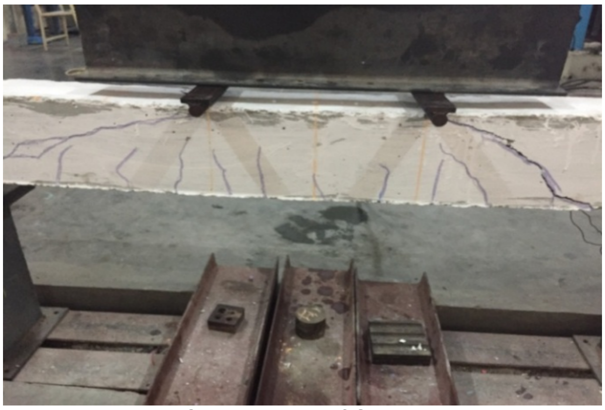

Fig. 4- Crack pattern of Q2 specimen.

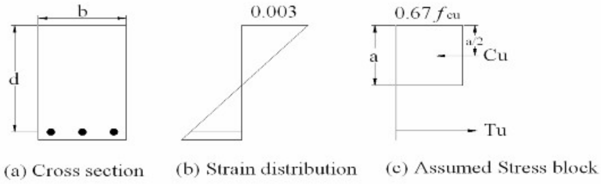

Fig. 5 - Stress Distribution in Concrete.

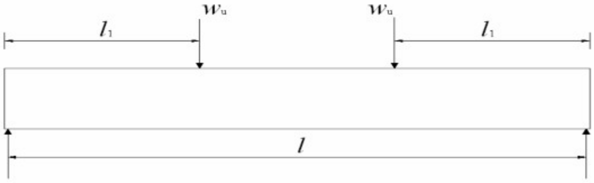

Fig.6-Loading arrangement.

higher than that of P2 specimen. It was recorded that the Q1, Q2 specimens showed increased load carrying capacities compared to P1 and P2 specimens. The marginal increments in ultimate load carrying capacity for Q1, Q2 specimens when compared to the P2 were 9.34%, 11.53%. Steel fibres significantly affected the flexural strength of concrete due to their higher rigidity and modulus of elasticity. Likewise, steel fibres are larger in size and have hooked ends, which have greater ability to hold the materials in contact to withstand the loading compared to polypropylene fibre [14]. Subsequently, the crack pattern is observed to be less for the specimen containing the steel fibres [15].

The theoretical ultimate load is calculated for the control beam by assuming rectangular stress distribution in concrete as shown in Figure 5.

For equilibrium,

Compression C_u= Tension T_u

The depth of the stress block 'a' is obtained from $0.67 f_{cu} b\ a = A_{st} \sigma_{sy}$

Where, f_{cu}= cube compressive strength

b = breadth of beam

A_{st}= area of tension reinforcement

σ_{sy}= yield tensile stress of steel

Ultimate moment of resistance of the beam section $M_u = C_u$ x lever arm

$$M_u = 0.67\ f_{cu} b\ a(d-a/2) \qquad (1)$$

The maximum moment due to dead and live loads for the given loading arrangement as shown in the Figure 6 is

$$M_u = (Wl^2/8) + W_u l_1 \qquad (2)$$

Where

W-dead load intensity per unit length, l-span of the beam, W_u - two point load with symmetry, l_1- concentrated load distance from support.

By equating the equations (1) and (2) , theoretical ultimate load was determined as 96.3 kN for control beam specimen.

The ultimate load carrying capacity of the control beam at mid-span was computed

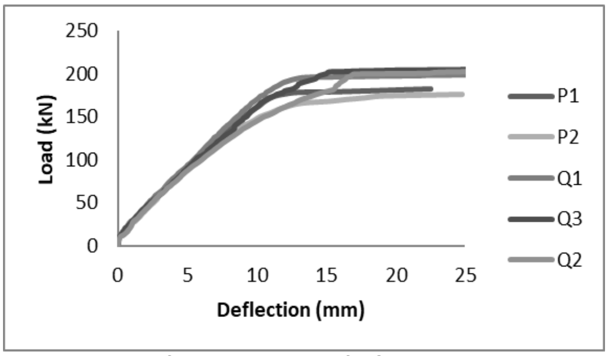

Fig. 7 - Load- Deflection behavior o.f RC beam with and without STF

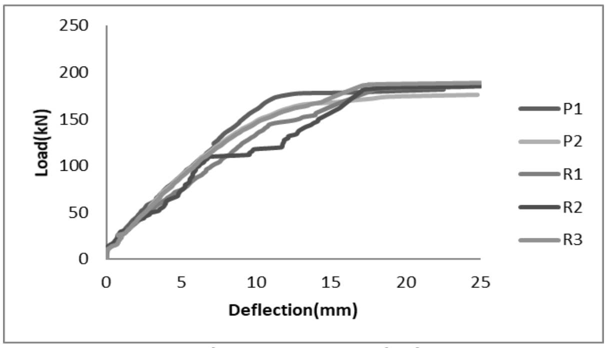

Fig. 8 - Load – Deflection behavior of RC beam with and without PPF.

theoretically as 96.3 kN as per IS 456-2000 [13]. . The theoretical and experimental load results were compared and illustrated in Table 3. The ratio of experimental to theoretical of control beam for Q3 specimens was 2.13. Similarly R2 specimen and S1 specimen shows the ratio of 1.94 and 2.26 respectively. As seen in Table 3, an increase in ultimate load of R1, R2, R3 specimens over that of P1 specimen varied from 4.54% to 7.39% depending on the age of specimen and volume fraction of fibres. Figure.8 illustrates the load-deflection curves of RC beams with and without PPF.PP fibres are short and have lower rigidity and elastic modulus compared to those of steel fibres. Additionally, PP fibres held only on micro-cracks and did not contribute much to the flexural strength.

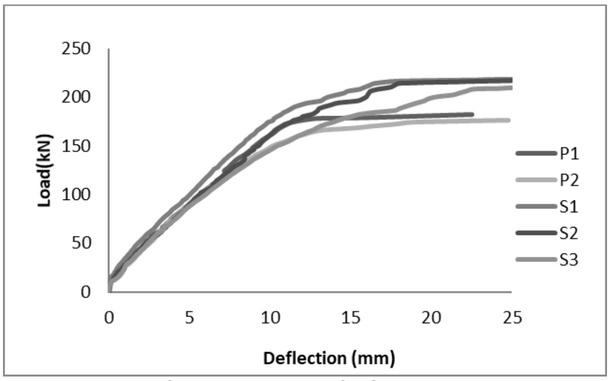

Fig. 9 - Load-Deflection behavior of RC beam with and without Hybrid fibres.

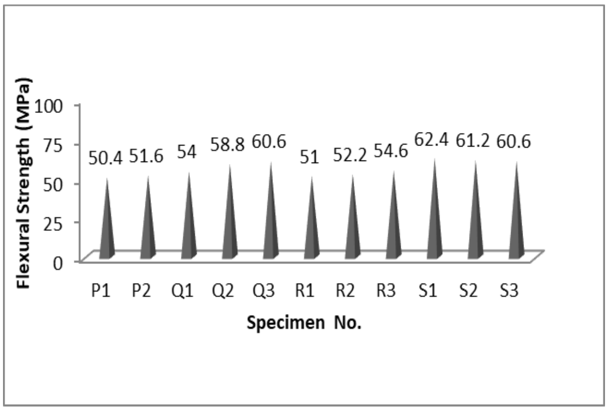

Fig. 10 - Flexural strength.

The ultimate load improvement of hybrid fibre reinforced beams (S1, S2, S3 specimens) ranged from 19.88% to 23.86%.Figure.9 shows the load-deflection curves of RC beams with and without hybrid fibre. The results of this study clearly demonstrate that the inclusion of steel and PP fibres Impacts the load carrying capacity of beam specimens in an unexpected way. At the point when steel fibres are supplanted with polypropylene fibres, the load carrying capacity diminishes in correlation with mix containing steel fibres, yet increased with concrete free from filaments. This increase might be because of fibres converging the crack in the tension half of the reinforced beam. A portion of the hooked-end steel fibres turned out to be straight under substantial static loads they were subjected to during pull out stage. Fibres extend themselves in the obliged crack face, which isolates the crack portion by giving an extra energy absorbing mechanism. This thusly arrest the micro cracks in concrete [16]. The results shown in Figure.9 indicate an increase in the content of PP fibres in the hybrid mixes lead to considerable reductions in flexural strengths of the mixes.

The shear strength of the beams enhanced due to the filling ability of fibres throughout the cracks, as well as tension of stirrups is likewise deferred in flexure due to the addition of fibres.A ductile material is on that experience vast strains while opposing the loads. When load is applied to RC members, the term ductility suggests the capacity to manage noteworthy inelastic deformation before failure [17]**.** It was observed that flexural failure occurred for P1 specimen. Likewise more extensive shear cracks were found in the case of beam free from fibres. At the end of the test, shear failure were noted. Soon after the peak load, the diagonal cracks propagate in flexure. When the fibre percentage increased, comparable failure pattern was seen in the beams. Because of addition of fibres, stirrups are less focused while loading on specimen and the flexural failure of stirrups deferred.Flexural failure was seen in the fibre reinforced concrete beams, thus indicating higher ductility in the tensile zone.

4.2. Flexural strength

Based on bending stress equation M/I=f/y=E/R, Flexural strength of the beam was calculated by using the expression PL/BD^2, where cross section of the beam (BXD in mm), length of the beam (L in m), ultimate load (P in kN).From the Figure.10, the flexural strength of the all specimens shows improved trend as compared with P1 specimen. The increment value of flexural strength of P2 specimen may due to the fact that 10 % bagasse ash inclusion in plain cement concrete increases the aggregate paste bond through the densification of the transition zone and the formation of more calcium silicate hydrate. It was noted that the addition of fibres in the plain cement concrete increases the flexural strength. Increased Flexural strength of Q1 to Q3 specimens varies from 13.06% to 16.47% when compared with P1 specimen. The flexural strength of R3 specimens was up to 7.38% greater than that of companion concrete P1 specimen free from filaments. Among the series Q and R specimens, the Q series specimens have shown enhanced flexural strength. The enhancement of flexural strength of hybrid fibres (S series specimen) ranged between 19.88% and 23.86%. S1 specimen shows higher flexural strength of 23.86% when compared with all other specimens. Hence the improved flexural strength in fibre reinforced concrete may be due to the reduction in crack width, size and improved deformation capacity.

4.3. Ductility

Ductility of a structure is its ability to undergo deformations beyond the initial yield deformation, while still sustaining the load. The deformations can be considered with displacement and curvature. Table 4 shows the displacement and curvature values along with ductility index. Ductility index is defined as the ratio of curvature and displacement ductility. Displacement ductility and curvature ductility results show that the ductility value increases with increase in the percentage of fibre content. Average displacement ductility increments in specimens were of 6.57 mm

Table 4

Ductility Values & Flexural Toughness Indices

Specimen No.	Displacement Ductility μ_Δ(mm)	Curvature ductility μ_Φ(mm)	Ductility Index (μ_Δ / μ_Φ)	Cumulative Ductility Index	FTI as per ASTM (I_5)	FTI as per ASTM (I_{10})	T_{JCI} (kN-mm)
P1	5.55	5.47	0.987	0.987	7.682	23.250	2112
P2	5.85	5.15	0.964	0.964	7.880	22.380	1920
Q1	6.48	6.90	1.065	1.065	7.926	23.111	2160
Q2	6.52	7.11	1.092	2.157	7.710	21.460	1896
Q3	6.72	7.79	1.160	3.317	8.029	24.743	2160
R1	4.22	5.91	1.034	1.034	7.458	21.052	1776
R2	4.35	6.30	1.062	2.096	7.444	21.426	1536
R3	5.41	7.06	1.120	3.216	7.750	23.563	1896
S1	7.14	10.8	1.519	1.519	7.474	20.763	2208
S2	6.49	8.26	1.274	2.793	8.000	23.452	2148
S3	5.92	6.77	1.145	3.938	7.742	21.431	1908

in Q series, 4.66 mm in R series and 6.51 mm in S series respectively. Similarly increments in specimens with respect to curvature ductility were of 7.26 mm in Q series, 6.42 mm in R series and 8.61 mm in S series. Average values of both ductility shows that Q & S series specimens contribute more towards the inelastic deformation without substantial diminish in the load carrying capacity [6]. As evidence, the cumulative ductility index of Q & S series is higher when compared with R series specimens. R series specimen values of both displacement and curvature were marginally high when compared with P1 and P2 specimens. As an upshot, ductility index value increases when the fibre percent increases both in steel and polypropylene fibre.

4.4. Flexural Toughness

Flexural toughness for fibre reinforced concrete was determined as specified by ASTM C1018 [18]. The ASTM C1018 method is based on calculating the quantity of energy required for initial crack of the beam to deflect and later with multiples of the initial crack mid-span deflection. The flexural toughness indexes (FTI) (I_5, I_{10}, I_{30}) were used to find out the flexural toughness as ratios of the area of the load –mid span deflection curve up to deflections of 3, 5.5 and 15.5 times the initial crack mid span deflection. The incremental value of I_5, I_{10}andI_{30}indicates that concrete has much better flexural toughness. When the initial crack happens, the corresponding mid-span deflection was noted. The FTI have a minimum value of unity for elasto-plastic material. The Japanese Concrete Institute (JCI method)[19] recommends toughness as the energy required for deflecting the beam to a half span deflection of 1/150 of its span. Table 4 enlists the difference of flexural toughness indices (I_5, I_{10}) of the high performance concrete blended with 10 % bagasse ash with increments in percentage of steel and polypropylene fibres and hybrid fibres at age of 28 days. The FTI of Q3, R3 and S2 specimens increased when compared with P1 and P2 specimens. However, the variation in the percentage of fibres (0.25, 0.50 and 0.75 STF, 0.15, 0.30 and 0.45 PPF) in high performance concrete has adverse effect of flexural toughness. Inclusion of fibres increases toughness value T_{JCI} to certain extent. In all the specimens, the values of I_5, $I_{10}$are less than 5 and 10 respectively. Hence, the used fibres are elastoplastic material. The development of internal cracks was not prolonged in the concrete beam due to the presence of independent (Q and R Series specimens) and hybrid fibres (S series). As an outcome, the flexural toughness of the concrete is enhanced.

5. Conclusions

The study of bagasse ash blended high performance concrete beams with steel, polypropylene and hybrid fibres was carried out to understand the different properties. The following conclusions are observed from this study:

1. The ultimate load of 10 % bagasse ash (P2 specimen) blended beam was 3.4% increase compared to that of beam without bagasse ash (P1 specimen). Similarly the maximum ultimate load was attained by 0.85 % STF and 0.15% PPF (S1 specimen) with increments of 23.86 % and 19.88 % compared to that of plain concrete beam with and without bagasse ash (P1 specimen and P2 specimen). In case of Q & R series, ultimate load was 12.63% & 7.39% increase with respect to P1 specimen,
2. The ratio of experimental to theoretical data of load carrying capacity was evaluated for all the specimens .From this maximum was observed by 0.85 % STF and 0.15% PPF (S1 specimen) with increments of 5 % and 16.57% contrast with specimens of steel and polypropylene fibres (Q and R series specimens).
3. The improvement in ductility index was achieved as the fibre content increases both in

steel and polypropylene. The maximum cumulative ductility index was 3.938 for hybrid fibres(S series specimens),

4. Addition of fibres has shown immense performance on the FTI of 10 % bagasse ash blended high performance concrete. The values of FTI were maximum with increase in the steel fibre (Q series specimens) but not in the polypropylene fibres (R series specimens). Similarly, the values of FTI of hybrid fibres specimen have also shown decrease in trend when polypropylene fibre content increase, and

5. The contribution of fibres to the flexural toughness of high performance concrete with 10 % bagasse ash is performed well up to certain increment in the fibre content.

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