Flexural performance of over-reinforced beam containing hybrid fibres with GGBS

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Abstract

In this study the flexural performance of the over reinforced beam with hybrid fibres and GGBS has been experimentally investigated. Concrete is generally brittle material and it fails in brittle nature which is a major drawback in the over reinforced section. The brittle nature of the concrete can be changed by addition of fibres, proper confinement and addition of certain admixtures. Along with the confinement, Steel fibre, Glass fibre and GGBS were used in this study. Four different volume fractions (0.5%, 1.0%, 1.5%, and 2%) of hybrid fibre with 20% GGBS (as a replacement of cement) were used in this investigation. A total of 13 numbers of beams of size 120 mm × 200 mm × 2100 mm was casted. The load deflection curve, ductility index, moment curvature and flexural rigidity were investigated in this study. The overall flexural performance of the over reinforced beams has been increased by having the confinement, addition of fibres and with the presence of GGBS.

Keywords Flexural performance · Hybrid fibres · Steel · Glass · GGBS · Over reinforced beam

1 Introduction

Ductility is the one of the major property in the construction of structural elements. Especially in beams, the ductility plays a vital role to sustain the loads. In reinforced cement concrete, steel will possess a good ductile behaviour comparatively than the concrete. Concrete is generally brittle material and it fails in brittle nature [2]. In over reinforced beam sections fail brittle since concrete reaches its maximum permissible stress prior than the steel, which is a major drawback of in the design of over reinforced sections [10]. The brittle nature of the concrete can be changed by addition of fibres, proper confinement and addition of certain admixtures. Addition of fibres in concrete as a discrete component will enhance the ductile property of concrete [4]. In recent days the technique of using more than one type of fibre in concrete leads to the development of Hybrid Fibres Concrete (HFC). Among different types of HFC, the combination of stiff and flexible fibre has been used [3]. Stiff fibre will arrest the

propagation of crack at the initial stage itself while the flexible fibre will arrest the crack propagation at its post cracking stage [7]. Steel fibre is the one of the commonly used stiff fibre and for flexible fibre Glass fibre was chosen [6]. Though many researchers have already studied steel fibre with the flexible fibres like Polypropylene, Polyolefin and synthetic fibres comparatively glass fibre possess a unique and new combination among them [8]. Due to the lack of workability the usage fibres has been limited. By giving proper confinement through the stirrups, the ductility can also be enhanced. The confinement is done by reducing the spacing of stirrups at the mid span region of the beam in which the bending moment is maximum [1]. With addition to that admixtures may also be added to enhance the ductility of the structures [9]. Usage by products materials like silica fume, fly ash and ground granulated blast furnace slag (GGBS) were used as admixtures in concrete which will leads to the decrease in consumption of cement and development in eco friendly concrete. Among the admixtures, GGBS is a by product which can

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be obtained from the manufacturing process of iron. The chemical composition of GGBS relies very similar to the ordinary Portland cement. The formation of CSH gel is more in GGBS when compared to the OPC which is a major cause for attaining the strength in concrete [5]. Hence the ductility of the concrete can be enhanced by the hybrid fibres, confinement and admixtures. From the exiting literature, no study has been carried out to determine the flexural behaviour of over reinforced beams with confinement, hybrid fibres and GGBS.

This paper presents an experimental investigation on flexural behaviour of hybrid fibre-reinforced GGBS concrete. Flexural behaviour and ductility were studied. Though many researchers studied the flexural behaviour of beams and steel fibre beams, so far no study has been made to highlight the flexural behaviour of beams containing steel and glass fibre with GGBS. Thus, this paper focuses on a hitherto unexplored research area. The objective of the paper was to study flexural behaviour of hybrid fibre-reinforced GGBS concrete with confinement in over reinforced beams. Laboratory scale beams were cast and tested under two-point load system to study the yield load, ultimate load, first cracking load, failure modes, crack patterns, ductility index and flexural rigidity.

1.1 Research significance

As per Indian code of practice, the design of the over reinforced sections has been restricted mainly due to the brittle failure of the concrete. Hence in this research work the beams were purposefully designed as an over reinforced section to enhance the ductile behaviour by confinement and with the addition of the hybrid fibres. Along with the confinement in the mid region of the beams, the steel and glass fibres were added to arrest the crack propagation at initial and post stage of cracking. The actual neutral axis depth (x_u) of the designed beam is greater than the critical neutral axis depth ($x_{u\max}$), this relation shows that the beams are over reinforced.

For the given section where $b = 120$ mm; $D = 200$ mm; $d = 167$ mm; M25 grade of concrete & Fe415 grade steel; 2 numbers of 16 mm diameter bars has been used.

Depth of Neutral Axis: (x_u)

$$x_u = 0.87 f_y \cdot A_{st} / 0.36 f_{ck} b$$

$$x_u = 134.39 \text{ mm}$$

$$\text{For } x_{u\max} = 0.48 d = 80.16 \text{ mm}$$

$$x_u > x_{u\max}$$

Hence it is over reinforced section.

Check for reinforcement: $A_{st_{req}}$ = Area of the steel required; $A_{st_{pro}}$ = Area of the steel provided.

$$A_{st_{req}} = x_{u\max} 0.36 f_{ck} b / 0.87 f_y$$

$$A_{st_{req}} = 242 \text{ mm}^2$$

$$A_{st_{pro}} = 2 \text{ numbers of } 16 \text{ mm diameter bars}$$

$$A_{st_{pro}} = 401.92 \text{ mm}^2$$

$$A_{st_{pro}} > A_{st_{req}}$$

Hence it is satisfied.

2 Materials and methodology used

Ordinary Portland Cement (OPC) 43 grade conforming to IS 12269-1987 with a specific gravity of 3.08 was used in concrete mixtures. River sand passing through 4.75 mm IS sieve conforming to grading zone II of IS 383:1970 and having a specific gravity of 2.45 was used in this work. Crushed aggregate available from local sources with a maximum size of 20 mm and conforming to IS 2386:1963 was used as coarse aggregate in this study. Steel fiber having length a of 30 mm with diameter of 0.75 mm and glass fiber having a length of 25 mm with diameter of 0.5 mm were used. The aspect ratio of 40 for steel fiber and 50 for glass fiber were kept constant. Four different volume fractions (0.5%, 1.0%, 1.5%, and 2%) of hybrid fiber with 20% GGBS (as a replacement of cement) were used in this investigation.

2.1 Reinforcement details

Heavy reinforcement section was designed, ensuring that the beam has to fail in the concrete in the over reinforced section. The over reinforced beam size has been kept as per the limitations given by the national building code. Adequate two legged stirrups have been provided to take the shear failure, but at the mid span region the stirrups spacing was reduced to give the confinement in the concrete section. The side cover was also kept as nominal for the moderate environmental condition.

- Beam size: 120 mm × 200 mm × 2100 mm
- Reinforcement: 2 # of 16 mm diameter bar,
- Bottom cover—20 mm
- Side cover—20 mm
- Stirrups: 2 legged 8 mm diameter @ 120 mm c/c and 2 legged 8 mm diameter @ 100 mm c/c [only at mid span]

2.2 Mixing and curing

Based on trial mixes for different proportions of constituents, the final design mix was prepared for M25 grade of concrete as per IS 10262:2009. The concrete mix proportion and w/c ratio are presented in the Table 1. The hybrid

Table 1 Mixing proportion for 1 m³

Mix	W/C	Water (kg/m ³)	Cement (kg/m ³)	Fine aggregate (kg/m ³)	Coarse aggregate (kg/m ³)	Volume fraction V _f	Steel fiber content (kg/m ³)	Glass fiber content (kg/m ³)	GGBS (20% replacement) (kg/m ³)
Ref	0.5	195	390	712.64	1105.68	0	0	0	0
SC-0.5-100	0.5	195	312	712.64	1105.68	0.5	12.01	0	78
HC-0.5-80-20	0.5	195	312	712.64	1105.68	0.5	9.61	2.40	78
HC-0.5-60-40	0.5	195	312	712.64	1105.68	0.5	7.20	4.81	78
SC-1-100	0.5	195	312	712.64	1105.68	1.0	24.03	0	78
HC-1-80-20	0.5	195	312	712.64	1105.68	1.0	19.22	4.81	78
HC-1-60-40	0.5	195	312	712.64	1105.68	1.0	14.42	9.61	78
SC-1.5-100	0.5	195	312	712.64	1105.68	1.5	36.05	0	78
HC-1.5-80-20	0.5	195	312	712.64	1105.68	1.5	28.84	7.21	78
HC-1.5-60-40	0.5	195	312	712.64	1105.68	1.5	21.63	14.42	78
SC-2-100	0.5	195	312	712.64	1105.68	2.0	48.06	0	78
HC-2-80-20	0.5	195	312	712.64	1105.68	2.0	38.44	9.62	78
HC-2-60-40	0.5	195	312	712.64	1105.68	2.0	28.83	19.23	78

concrete is manufactured by as similar to the classical concrete.

The castings of beams were shown in the Fig. 1. Initially the dry materials, Cement, Aggregates and Sand are mixed. Further, fibres were added into the dry mixture for another 1 min. The fluid part of the mixture was then added to the dry materials and the mixing continued for further about 4 min to ensure even distribution of fibers in the fresh concrete. The beam was further divided into three halves to place the hybrid fibre GGBS concrete in the mid span region of the beam which is one-third of the overall length of the beam. The concrete was placed simultaneously in three halves of the beams. Compaction of the concrete was done with the help of 30 mm needle vibrator. After casting the beam specimen, it was demoulded after 24 h and curing was done using the gunny bags over a period of 28 days. After 28 days of curing the beams were

tested under two point loading condition. A total of 13 beams have been cast for this study.

2.3 Testing set up

After 28 days of curing the beams were kept in the loading frame to test the flexural performance under two point loading condition. The testing set up was shown in the Fig. 2.

To determine the deflection, the dial gauges were placed in the three different positions. One of the dial gauge is exactly at the midpoint of the beam and other two dial gauges were placed under the loading points. The strain gauges were also fixed at top and bottom of the beam to determine the strain at the compression and at the tension region.

Fig. 1 Casting of beams

Fig. 2 Testing set up

3 Test and results

3.1 General observations on crack pattern

The formation of the initial crack is visually indentified in the conventional beam and later on the crack has been developed with increase in load from the bottom to the top side of the beam. But in case of hybrid beams the initial cracks were very hard to find and the width of the crack is also minimum while comparing to the conventional beam. This shows that the presence of the hybrid fibre in the mid span region of the beam will reduce the propagation of the cracks. Increase in hybrid fibre content leads to decrease in the formation of cracks. In hybrid beams the cracks have been developed with increase in load but after the beams reaches its ultimate strength, it undergoes a long term deformation which is quite remarkable to see in an over reinforced sections. And even when the load is removed, the hybrid beams were able to merely regain its original position which shows a good elastic property (Fig. 3).

3.2 Load deflection

The deflection was measured at three different points in the beam. One is at the mid span and other two points were directly below the two point loading condition. The first cracking load, yield load and peak load for each specimen were given in the Table 2. The first cracking load is the value of the load at the end of the initial linear zone in the load–deflection curve. The yield load is the load when the specimen yielded, which was 75% of its ultimate strength and the peak load is the maximum load of the load–deflection curve. The beam's deflection until the initiation of cracks increased linearly and was proportional to load. After the initial cracking, deflection increased non-linearly until the maximum load was reached. Apart from the reference mix all beams sustained certain amount of deformation even after it reaches ultimate load. This shows the evident on the ductile behaviour of the over reinforced beams which actually influenced by the addition of fibres and confinement. The maximum deflection has been observed at mix HC-1-60-40 was 11.82 mm which are 51.2% greater than the conventional beam. Increase in

Fig. 3 Crack failure pattern

Table 2 Test result in flexure and ductility index

Beam specimen	Initial cracking		Yielding state		Peak state		Ultimate deflection Δu (mm)	Ductility index	
	P_{cr} (kN)	Δ_{cr} (mm)	P_y (kN)	Δ_y (mm)	P_p (kN)	Δ_p (mm)		Δ_p/Δ_y	$\Delta u/\Delta_y$
Ref	8	0.51	52	4.12	72	5.29	5.76	1.28	1.40
SC-0.5-100	12	0.99	80	5.32	96	6.90	7.12	1.30	1.34
HC-0.5-80-20	16	1.36	86	5.48	104	9.77	11.23	1.78	2.05
HC-0.5-60-40	12	1.39	90	6.08	112	9.47	11.16	1.56	1.84
SC-1-100	12	1.02	82	5.33	100	8.59	10.78	1.61	2.02
HC-1-80-20	16	1.43	92	4.93	108	8.23	10.53	1.67	2.14
HC-1-60-40	12	1.57	102	7.32	132	11.82	16.26	1.61	2.22
SC-1.5-100	16	1.69	82	6.21	108	8.84	10.92	1.42	1.76
HC-1.5-80-20	12	0.92	94	5.36	116	7.67	12.35	1.43	2.30
HC-1.5-60-40	20	0.96	100	6.84	120	10.92	15.36	1.60	2.25
SC-2-100	16	1.58	86	6.15	112	9.92	12.83	1.61	2.09
HC-2-80-20	12	0.75	104	7.12	120	8.36	14.29	1.17	2.01
HC-2-60-40	24	2.61	108	7.86	124	11.08	16.38	1.41	2.08

Fig. 4 Load deflection curve at 0.5% volume fraction **Fig. 5** Load deflection curve at 1.0% volume fraction

hybrid fibre content delays the formation of cracks which is clearly observed at the mix HC-2-60-40 and the load taken to form the initial crack is 50% greater than the conventional beam.

From the load deflection curve it was clearly observed that the inclusion of fibre will increase the energy absorption capacity of the beams. Particularly the beams with glass fibre possess a very good long term deformation compared to the beams with steel fibre and with the reference beam. Increase in glass fibre content increases the load–deflection behaviour at every fibre volume fractions which were shown in Figs. 4, 5, 6 and 7. This shows the post strain absorption capacity was highly influenced by adding the glass fibre.

3.3 Ductility

Energy absorption in a material without critical failure is often called as ductility and it also relates to the amount

Fig. 6 Load deflection curve at 1.5% volume fraction

of inelastic deformation which a material or structure undergoes before it failure. The deformation of this structural member has been measured during the transition

Fig. 7 Load deflection curve at 2.0% volume fraction

zone from elastic to plastic zone. The brittle failure can be prevented in a structure which undergoes large plastic deformation with little decrease in strength. Generally the ductility can be determined by deflection ductility, rotational ductility and curvature ductility. Among all the methods, deflection ductility is the essential and simple method which can be determined with the help of mid-span deflection. Ductility index is conventionally defined as the ratio between the mid-span deflection at the beam ultimate load and the mid-span deflection at the yielding load of the tensile steel reinforcement at the central support. In this study, therefore, the deflection ductility index has been calculated by the use of the equation given below Eq. (1).

$$\mu = \Delta u / \Delta y \quad (1)$$

where μ is the ductility index of the member, Δu is the deflection of the member at the ultimate load, and Δy is the deflection of the member at the yielding load. The yield point has been taken as 80% of its ultimate load value after reaching the peak, while the latter is obtained by linearly interpolating the displacement at 75% of the theoretical load.

The highest value for ductility index is 2.30 attained at HC-1.5-60-40 which is 39.13% higher than the conventional beam. And even the ductility index has been found better in increase with glass fibre content in the hybrid fibre. The post tension cracks may get arrested by the glass fibre and this flexible fibre yields more than the steel fibre. Comparatively all the hybrid mix ratios will shows a better ductile performance than the conventional beam and the beams containing the steel fibre. And particularly at all 60–40 ratio of hybrid fibre the ductility enhanced more than the 80–20 hybrid ratios. And hence the ductility of the over reinforced beam has been enhanced by the addition of hybrid fibres.

3.4 Moment curvature

Moment–Curvature diagrams were generated for all the beams based on the concrete strain and steel strain. Curvature is computed from the average longitudinal compressive and tensile strains at the top and bottom of the beam assuming a linear strain profile across the cross section using the formula

$$\text{Curvature, } \Phi = (\epsilon_c + \epsilon_s)/d$$

where ϵ_c , Average longitudinal compressive strain in at the concrete fibre at the center of the flange; ϵ_s , Average longitudinal tensile strain at the centroid of the tension steel; d , Distance between the compression and tension strain locations considered.

The strain gauges were used to create a strain profile for the height of the beam. The planar sections were assumed to remain planar. Therefore, the strain profile results could be used to determine the curvature. Individual gauges were used until their readings became unreliable due to cracking in the underlying concrete. The ultimate strain values at top and bottom of the beam has been taken to calculate the curvature. The curvature of the cross section could be computed from these results. Table 3 shows the moment–curvature of the beams at 28th day respectively. The results show that increase in moment leads to increase in curvature. The maximum value for moment was reached at HC-1-60-40 is 39.6 kN-m which is 45.45% higher than the ordinary conventional beam. For curvature the geometric deformation occurs maximum at HC-1-60-40 is 4.92×10^{-5} which is 73.78% greater than the reference beam. And the moment curvature relationship is very similar to the load deflection curve for the 60–40 ratios of hybrid fibre. Inclusion of glass fibre leads to the greater deformation and ductility at 80–20 and 60–40 ratios of hybrid beams. The presence of hybrid fibre plays a major role along with the confinement which changes the strain rate. In each sample the synthetic fibre (Glass fibre) content has been varying along with the confinement which may cause the change in strain rate. The strain rate has been varied at the top and bottom of the sections due to the provision of additional reinforcement (Hanger Bars) in the compression zone to tie and for holding the stirrups. In addition to that confinement provided at the mid span region alone may cause the non linear strain profile with varying compressive strain in concrete and tensile strain in steel. The neutral axis represents the centre of gravity of the beam. In an over reinforced beam the quantity of steel is increased and thus the neutral axis shifts towards the reinforcement. Similarly in an under reinforced beam the quantity of reinforcement is decreased thus the neutral axis shifts away from the tension side. In each and every beam sections the quantity of

Table 3 Moment–curvature

Specimen ID	Ultimate load (kN)	Strain in top E_c	Strain in bottom E_s	Moment (kN-m)	Curvature (mm)
Ref	72	0.00098	0.00124	21.6	1.29E-05
Sc-0.5-100	96	0.00427	0.00178	28.8	3.52e-05
Hc-0.5-80-20	104	0.00359	0.00193	31.2	3.21e-05
Hc-0.5-60-40	112	0.00278	0.00290	33.6	3.30e-05
Sc-1-100	100	0.00423	0.00291	30	4.15e-05
Hc-1-80-20	108	0.00315	0.00159	32.4	2.76e-05
Hc-1-60-40	132	0.00464	0.00382	39.6	4.92e-05
Sc-1.5-100	108	0.00298	0.00214	32.4	2.98e-05
Hc-1.5-80-20	116	0.00294	0.00242	34.8	3.12e-05
Hc-1.5-60-40	120	0.00276	0.00187	36	2.69e-05
Sc-2-100	112	0.00318	0.00391	33.6	4.12e-05
Hc-2-80-20	120	0.00389	0.00221	36	3.55e-05
Hc-2-60-40	124	0.00423	0.00315	37.2	4.29e-05

hybrid fiber content has been varied which may leads to the further variation in the strain rate.

3.5 Flexural rigidity

Flexural rigidity is the resistance of the beam to bending for given curvature. The common need for deflection analysis arises from materials testing, in which the transverse deflection induced by a bending load is measured. If we know the relation expected between the load and the deflection, we can “back out” the material properties (specifically the modulus) from the measurement. If the ratio of δ_u (Ultimate Deflection) to P (Ultimate Load) is measured experimentally, the modulus can be determined. A stiffness measured this way is called the flexural modulus.

In this study the value of the EI has been found on the basis of elastic deformation theory. Based on elastic deformation theory, the experimental flexural rigidity of a simply supported beam can be obtained by using Eq. (1). The flexural rigidity of the beams was determined after cracking. Table 4 shows the flexural rigidity values.

$$(E_c I) = PL^3 / 48\delta_u$$

where L is the span length of the beam, E_c is the elastic modulus of concrete.

The flexural rigidity reaches its peak at HC-1-60-40 is 414 kN/m² which is 80.67% higher than the reference mix. Addition of hybrid fibres may enhances the flexural rigidity by arresting the propagation of crack initially by steel fibre and later by glass fibre. Comparatively the beams containing steel and glass fibre does have more flexural rigidity than the beams containing steel fibre alone. This shows the good strain absorbing has been in the glass fibre than the steel fibre. Overall the flexural rigidity of the hybrid

Table 4 Flexural rigidity

Specimen ID	Ultimate load (kN)	Ultimate deflection (mm)	Flexural rigidity (EI) [kN/m ²]
Ref	72	5.76	80.02
SC-0.5-100	96	7.12	131.88
HC-0.5-80-20	104	11.23	225.34
HC-0.5-60-40	112	11.16	241.16
SC-1-100	100	10.78	207.99
HC-1-80-20	108	10.53	219.42
HC-1-60-40	132	16.26	414.11
SC-1.5-100	108	10.92	227.54
HC-1.5-80-20	116	12.35	276.40
HC-1.5-60-40	120	15.36	355.62
SC-2-100	112	12.83	277.24
HC-2-80-20	120	14.29	330.85
HC-2-60-40	124	16.38	391.88

fibre over reinforced beams has been increased than the conventional beam.

4 Conclusion

From the test results the following conclusions were made:

- The overall flexural performance of the over reinforced beams has been increased by having the confinement, addition of fibres and with the presence of GGBS.
- It is observed that the workability of the concrete was not get affected by the addition of fibres with GGBS.
- The flexural cracks were developed during the loading process and there no significant effect on the shear failure.

- In the load deflection curve, the maximum deflection is 16.26 mm over a peak load of 132 kN which is 64.57% higher than the conventional beam which possess a good ductile property.
- Except the conventional beam all other beams have a deformation even after it reaches its peak load.
- The energy absorption capacity was also increases by the addition of hybrid fibres and changes the failure mode of concrete from brittle to ductile. This change in behaviour will actually lead to arresting the propagation of cracks and the initial crack formation also delayed compared to the conventional concrete.
- At HC-1.5-60-40 the ductility index reaches its ultimate value is 2.30 which are 39.13% higher than the conventional beam.
- The maximum value for moment was reached at HC-1-60-40 is 39.6 kN m which is 45.45% higher than the ordinary conventional beam. For curvature the geometric deformation occurs maximum at HC-1-60-40 is 4.92×10^{-5} which is 73.78% greater than the reference beam.
- The flexural rigidity reaches its peak at HC-1-60-40 is 414 kN/m^2 which is 80.67% higher than the reference mix.
- Hence the flexural and ductile behaviour of the over reinforced can be enhanced by confinement of stirrups, addition of fibres with the presence of GGBS.
- This shows the inclusion of the hybrid fibres with proper confinement will make the concrete to fail in ductile manner which actually fails in brittle. Hence the failure mode of the over reinforced concrete beams can be changed and we may use or recommend the over reinforced sections for the safe design.

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Compliance with ethical standards

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