Flexural behavior of fiber reinforced lightweight concrete

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Abstract
In this research the flexural behavior of lightweight aggregate concrete with inclusion of steel and glass fiber was investigated. Pumice aggregate was used for the replacement of normal weight aggregate to reduce the density of concrete in order to achieve lightweight concrete. The methodology consisted of comparing the results of conventional reference concrete, plain. Light Weight Aggregate Concrete (LWAC) and fiber reinforced LWAC. The beams were produced with two types of fiber reinforced LWAC, plain LWAC and conventional concrete with similar compressive strength to allow for the comparison of structural performance of the beam. The fibers were added in the LWAC to reduce the brittleness of the concrete in order to increase the energy absorption capacity and to control the faster rate of crack development. In this research steel and glass fibers were added separately in three percentages of 0.5, 1.0 and 1.5 based on the weight of concrete. The hybrid combinations of steel and glass fibers were not adopted in this study. The beam specimen with 20% LWA and 0.5% steel fiber has the increase in load carrying capacity by 28% as compared to control beam.The ductility ratio of the same beam is 85% more than that of control specimen.

Keywords: Flexural behavior, Lightweight, steel fiber, glass fiber, density of concrete, brittleness of the concrete.

Introduction

High density concrete increases the dead loads of the building, which will increase the foundation loads of the building. In order to reduce the density of concrete lightweight aggregates were utilized to attain lightweight concrete. Lightweight concrete was used as a good fire resistant and sound insulation material. By using lightweight concrete, the sections of the building members were minimized thus decreasing the cost of the building (Duzgun et al., 2005; Nicolas et al., 2011; Topcu, 1997). Due to the lower modulus of elasticity of lightweight concrete, there will be adverse effect on the development and propagation of crack. However, recently by utilizing various additive the mechanical and strength characteristics of lightweight concrete may be improved. For the improvement of the structural performance of lightweight concrete, fibers of various types and proportions have been used. The significant role of fibers is to resist and delay the propagation of cracks increasing the flexural and fatigue characteristics of reinforced concrete (Lee Hyun-Ho, 2007; Lim & Oh, 1999). Nowadays the advantages of structural lightweight concrete have been numerous as compared to those of normal weight concrete (Dolby, 1995; Gao et al., 1997; Kayali et al., 2000; Swamy & Lixian 1995). Furthermore, high strength lightweight concrete production is desirable for practical applications (Hoff & Elimov, 1997). Due to this high strength, brittle failure is possible (Hsu & Hsu, 1994; Webb, 1993). To resist this brittle failure, fiber inclusion is considered for improving ductility.

With the inclusion of steel fibers in lightweight concrete, its load carrying capacity is increased nearer to the strength of ordinary concrete. Further, it increases the tensile and flexural strength, strength against explosive effects, resistance to dynamic and sudden loading. It is also effective in controlling the crack and decreasing the crack width. By adding steel fibers in lightweight concrete, the ability of deformation is increased and economical solutions are achieved by decreasing the weight of the concrete (Mohammadi et al., 2008; Wafa & Ashour, 1992). Steel fibers are still preferably used over macro-synthetic fibers due to its creep behavior which is the time-dependent strain that develops in concrete due to sustained stress (Pujadas et al, 2017). By the inclusion of fibers a comparative study was conducted to expose differences in terms of crack patterns and load-deflection behavior directly related with particularities of the pullout response (Pujadas et al., 2014; Blanco et al., 2015). By adding glass fibers in lightweight concrete, there would be an effective means of controlling shrinkage cracking. Glass fiber inclusion promotes multiple micro cracking thus reducing the crack width and improves the flexural performance and ductility of lightweight concrete. Introduction of glass fiber also controls the negative impacts of exposure to elevated temperatures (Faiz et al., 2002). The present investigation aims at studying the effect of pumice aggregate along with steel and glass fiber on structural behaviour of Fiber Reinforced Light Weight Concrete (FRLWC) in order to make it a viable structural material to be used in construction industry.

Material and methods

Methodology

In the present research, the mechanical and structural behaviour of FRLWC have to be assessed. The following methodology has been adopted in this research.

- To conduct the literature review on FRLWC.
- To determine the properties of the material used in FRLWC.
- To investigate the unit weight and compressive characteristics of FRLWC.
- To investigate flexural behaviour of FRLWC beams.
- Based on this experimental investigation, meaningful conclusions will be arrived at.

Cement

The cement used in this study for all the mixes was Ordinary Portland Cement with 53 grade, conforming IS 12269:2013. The compressive strength of cement mortar was found out as per IS 269-2015 as 29, 42 and 55 N/mm^2 at 3, 7, 28 days, respectively. The cement properties are shown in Table 1.

Table 1. Properties of cement. Source: Self-Elaboration.

Properties	Experimental Value
Standard Consistency	33%
Specific Gravity	3.15
Initial Setting Time	55 min
Final Setting Time	380min

Fine aggregate

Natural river sand conforming zone II as per IS 383:2016 was used as the fine aggregate. The sand was air-dried and sieved to remove any foreign particles prior to mixing. The specific gravity, fineness modulus and water absorption were determined and shown in Table 2.

Table 2. Properties of fine aggregate. Source: Self-Elaboration.

Properties	Experimental Value
Specific Gravity	2.62
Water Absorption	0.33%
Fineness Modulus	2.75

Coarse aggregate

Crushed granite coarse aggregate of particle size 20 mm having angular shape and confirming to IS: 2386 – 2016 was used for this investigation. In all the mixes, lightweight pumice aggregate was used as the replacement of coarse aggregate. The pumice aggregate used was saturated surface dried to avoid the water absorption in all the mixes. The properties of coarse aggregate and pumice aggregate are shown in Table 3.

Table 3. Properties of Coarse and pumice aggregate. Source: Self-Elaboration.

Properties	Coarse aggregate	Pumice aggregate
Specific Gravity	2.78	0.79
Water Absorption (%)	0.67	37.6
Impact value (%)	16.6	34.2
Crushing value (%)	29.3	49.2
Fineness Modulus	6.89	4.17

Steel fiber

Hooked steel fiber commercially available in the local market was used as fiber in this investigation. The diameter of the steel wire was found to be 1000 µm and relative density was 7.85. The tensile strength of steel fibers used was 600N/mm^2. The aspect ratio of steel fiber used was 50.

Glass fiber

The diameter of the glass fiber was found to be 8 to 15 µm and relative density was 2.54. The strength of glass fibers used ranged from 2000-4000N/mm^2. The aspect ratio of glass fiber used was 800. The properties of fibers and mix designation of various mixtures having the pumice and fibers are shown in Table 5 and 6, respectively.

Table 4. Properties of fibers. Source: Self-Elaboration.

Fiber Type	Relative Density	Diameter in µm	Tensile strength in MPa	Modulus of elasticity In MPa	Strain at failure in %
Steel	7.8	1000	600	210000	0.5-3.5
Glass	2.54	8-15	2000-4000	72000	3-4.8

Mix designation

The mix design of M40 grade concrete as per code IS 10262:2009 was done. Fifteen mixtures with varying percentages of lightweight aggregate, steel and glass fibers were used including control concrete. The normal weight aggregate was replaced with 20% and 40% of pumice lightweight aggregate, along with the inclusion of steel and glass fiber. The replacement with 20% and 40% of pumice aggregate without inclusion of fibers was taken as P1 and P2 concrete respectively. In this research steel and glass fibers were incorporated separately in three percentages of 0.5, 1.0 and 1.5 based on the weight of concrete. The mix designations for various mixtures are given in Table 5.

Table 5. Fiber and pumice aggregate percentage in mixes. Source: Self-Elaboration.

				Steel fibers						Glass fibers					
Mix Designation	Control Concrete	P1	P2	P1S1	P1S2	P1S3	P2S1	P2S2	P2S3	P1G1	P1G2	P1G3	P2G1	P2G2	P2G3
% of fibers	-	-	-	0.5	1.0	1.5	0.5	1.0	1.5	0.5	1.0	1.5	0.5	1.0	1.5
% of pumice aggregate	-	20	40	20	20	20	40	40	40	20	20	20	40	40	40

Casting procedure

All the specimens for testing were prepared at room temperature. Pumice aggregates were moistened and allowed to absorb water for 5 minutes to reduce water absorption of lightweight aggregates. The moistened pumice aggregates were mixed with cement and river sand in a drum mixer. Next, fibers were added into the drum and allowed to rotate at high speed to avoid clustering of fibers. After proper mixing, proper compaction of concrete was done using vibrating needle.

Experimental Investigation

In this research fifteen mixtures were cast to study the flexural behavior of fiber reinforced lightweight concrete, investigations were carried out on beam specimens for determining the ultimate load and load deflection characteristics. The beam dimension of 100 mm width, 150 mm depth and 1500 mm length was chosen for all mixes in this study. For the fabrication of structural beams, 8 mm and 12 mm diameters of reinforcement bars were used. Two numbers of 12 mm φ bars were used as tension reinforcement, two numbers of 8 mm φ bars were used as compression reinforcement and 8 mm φ 2 legged stirrups at 80 mm c/c spacing were used as shear reinforcement. These specimens were cured in water and tested for ultimate load, deflections and failure characteristics under 1/3 point loading in accordance to IS: 516-1999. In this study two point loading were applied using loading frame with a capacity of 400kN at the rate of 5kN per minute. The beam test setup with reinforcement bars were shown in Figure 1. The flexural behaviour of the beam inducing the formation of crack and ultimate failure are shown in Figure 2 to 4.

Figure 1. Beam test setup with reinforcement bars. Source: Self-Elaboration.

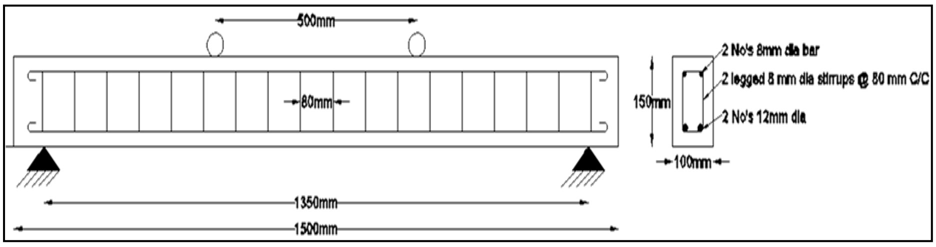


Figure 2. Formation of cracks in beam. Source: Self-Elaboration.

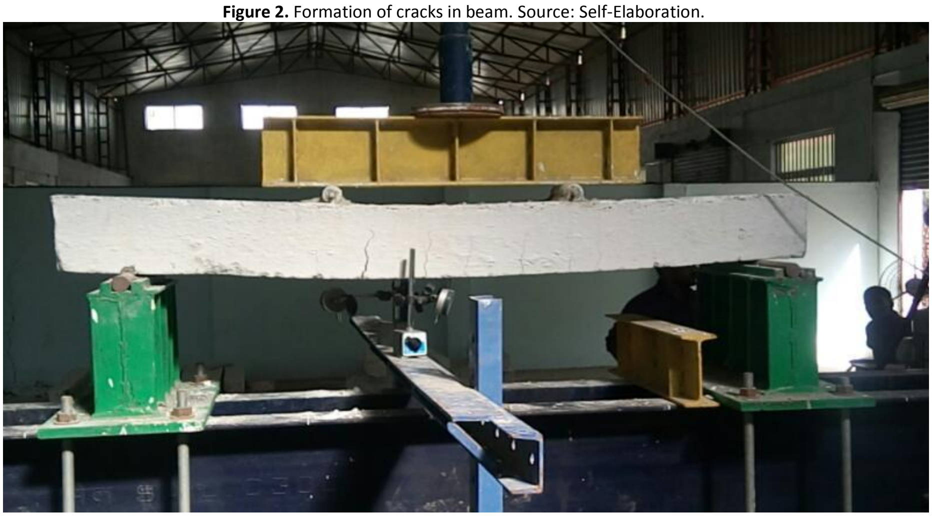


Figure 3. Flexural failure of beam. Source: Self-Elaboration.

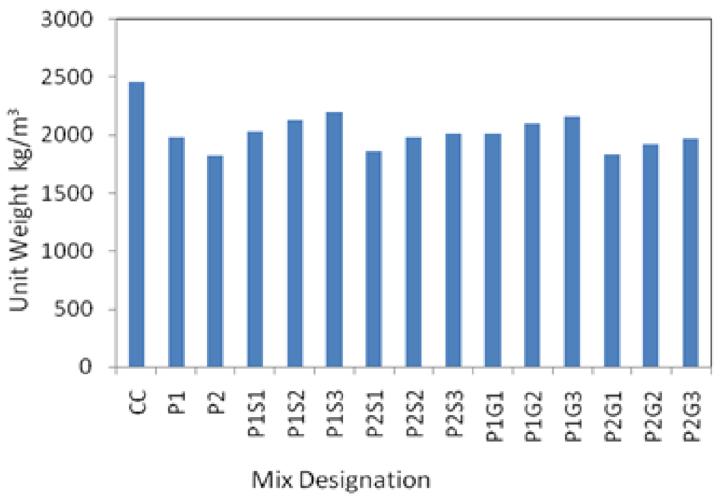
Figure 4. Beam failure at ultimate load. Source: Self-Elaboration.

Results and discussion

Unit weight of concrete

The main purpose of this experiment is to minimize the unit weight of concrete. In order to minimize unit weight of concrete, the coarse aggregate was substituted with pumice aggregate by 20% and 40%. A remarkable decrease in the unit weight was found when examined the unit weight of concrete. The control concrete had the unit weight of 2460 kg/m^3. The unit weight was decreased to 1985 kg/m^3 by replacing normal aggregate with 20% pumice aggregate (P1). In the same way the unit weight of concrete was further decreased to 1820 kg/m^3 by replacing with 40% pumice aggregate (P2). However the unit weight of concrete was increased by combining of steel and glass fibers. The mix P1 and P2 along with the inclusion of 0.5, 1.0 and 1.5% of steel fibers (P1S1, P1S2, P1S3, P2S1, P2S2, and P2S3) and glass fibers (P1G1, P1G2, P1G3, P2G1, P2G2, and P2G3) had the unit weight ranging from 1830 to 2200 kg/m^3. All the concrete mixes with and without fibers had the unit weight not as much the control concrete. Due to the higher specific gravity of fibers the increase in unit weight may occur. The unit weight for various mixes are shown in Figure 5 and Table 6.

Figure 5. Unit weight of FRLWC. Source: Self-Elaboration.



Compressive strength

Since the concrete is good enough in compressive strength, the core compressive strength of concrete should not be reduced due to any kind of replacement in the concrete component. The compressive strength for various mixes are shown in Figure 6 and Table 6. From the obtained results, it is clearly understood that the presence of pumice aggregate decreases the compressive strength of concrete.

Heavy weight aggregates are replaced by Pumice aggregates where their compressive strength were low and they cannot tolerate the desired compressive force. Even though lightweight concrete has been attained, it lost its core compressive strength. With a specific goal to build the compressive strength, steel and glass were added by different extents such as 0.5, 1.0 and 1.5 percentages. From the outcomes it was found that the P1 mix showed reduction in compressive strength by 29.9% and the P2 mix showed reduction in compressive strength by 41.6% when contrasted with the control concrete at 28 days. This reduction in compressive strength is because of the existence of cellular structure of light weight concrete in contrast to the normal weight concrete. The substitution of natural aggregate with 20% of pumice aggregate included with 0.5% of steel (P1S1) and glass fiber (P1G1) revealed increment in compressive strength by around 48% and 3.6%, respectively when contrasted with P1 mix at 28 days.

The substitution of natural aggregate with 40% of pumice aggregate included with 0.5% of steel (P2S1) and glass fibers (P2G1) revealed increment in compressive strength by around 42% and 6.2% respectively when compared to the P2 mix at 28 days. From the outcome, it is understood that 0.5% steel fiber in P1 and P2 concrete mix (P1S1 and P2S1) enhanced the compressive strength of concrete by around 48% and 42% individually when compared to P1 and P2 mix. Incorporation of steel fibers in light weight concrete matrix over 0.5% prompts to deduction compressive strength. By including steel fibers further, the compressive strength appeared to be negligible because of the complication in scattering of the fibers and concrete was not being completely compacted (Gao et al, 1997).

On the other way, glass fibers had relatively lower impact on the compressive strength. It was noticed that P1S1 and P1S2 had the ideal compressive strength with the rate increment of 3.8% and 1.7% when contrasted to control concrete at 28 days. It is plainly noticeable from the results displayed that it is possible to deliver light weight concrete with compressive strength more desirable than control specimen by establishing steel fibers of 0.5% to 1% which helps in decreasing the inertial load (Campione et al., 2001).

Figure 6. Compressive strength of FRLWC. Source: Self-Elaboration.

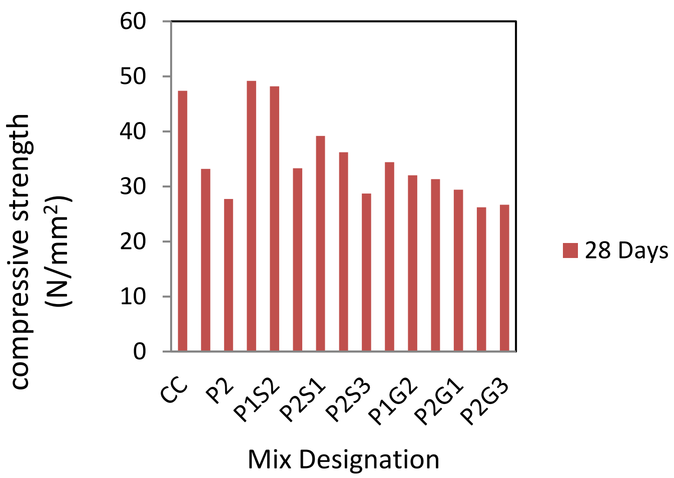


Table 6. Compressive strength and unit weight of various mixes. Source: Self-Elaboration.

Mix Id	Unit weight (kg/m³)	Compressive Strength (MPa)
CC	2459	47.4
P1	1985	33.2
P2	1822	27.7
P1S1	2030	49.2
P1S2	2133	48.2
P1S3	2207	33.3
P2S1	1867	39.2
P2S2	1985	36.2
P2S3	2015	28.7
P1G1	2015	34.4
P1G2	2104	32
P1G3	2163	31.3
P2G1	1837	29.4
P2G2	1926	26.2
P2G3	1970	26.7

Flexural performance

Table 7. Load deflection reading for various mixes. Source: Self-Elaboration.

Specimen	Load and deflection at first crack		Load and deflection at ultimate stage		Ductility ratio
	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)	
CC	82.1	6.75	95	16.4	2.43
P1	68.2	5.4	82	12.4	2.30
P2	62.1	5.82	86	11.6	1.99
P1S1	84.2	5.68	102	20.2	3.56
P1S2	102.3	6.35	119	27.02	4.26
P1S3	106.2	6.42	122	29	4.52
P2S1	86.7	7.07	98	18.2	2.57
P2S2	93.9	6.78	108	24.2	3.57
P2S3	99.1	7.4	114	27	3.65
P1G1	80.9	7.42	93	14.6	1.97
P1G2	80.2	6.82	92	13.9	2.04
P1G3	85.2	6.75	98	17.2	2.55
P2G1	74.4	7.42	87	14.6	1.97
P2G2	76.2	8.22	88	12.8	1.56
P2G3	77.3	7.89	89	13.5	1.71

Figure 7. Load deflection curve of LWC with steel fiber. Source: Self-Elaboration.

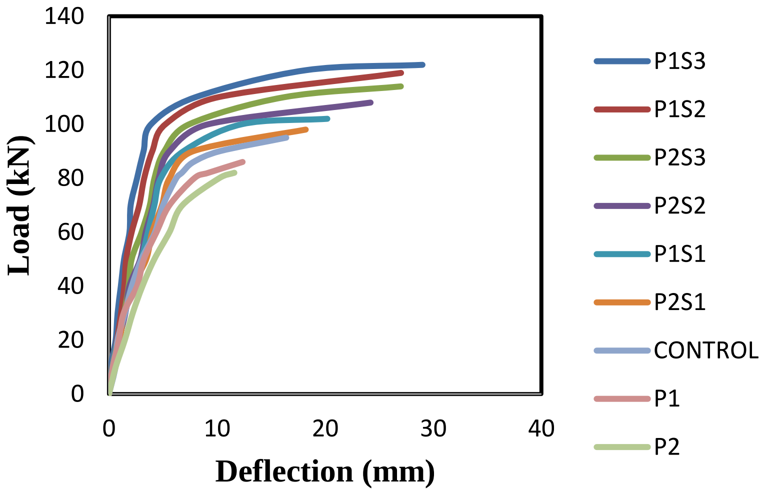
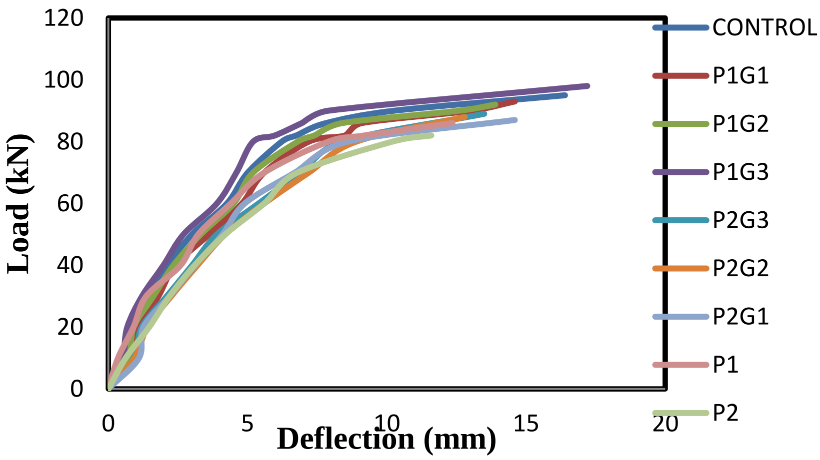


Figure 8. Load deflection curve of LWC with glass fiber. Source: Self-Elaboration.



The load deflection parameter at first crack formation stage and ultimate stage for various mixes are tabulated in Table 7. The load deflection curve with incorporation of LWC and steel fiber is shown in Figure 7. The load deflection curve with incorporation of LWC and glass fiber is shown in Figure 8. Lightweight concrete beam accelerate the rate of crack propagation due to their lower elastic modulus. However, fibers are used as an additive in order to increase the ductility behavior of lightweight concrete. The fiber inclusion promotes multiple micro cracking thus reducing the crack width and improves the flexural post cracking behaviour and the energy absorption capacity of the lightweight concrete. The crack propagation of concrete beams starts when the strain in the tensile field exceeds concrete strain. When the load increases, the beam would undergo maximum bending moment and reaches a yield strain of reinforcement at certain level of load. The important influence of the fibers is to delay the crack propagation in the tensile area of the lightweight concrete beams. The ductility ratio values for various mixes are shown in Table 7. Ductility is the deformation ability beyond initial yield deformation without loss in strength. From the result, it is observed that the ductility ratio of P1S3 and P1G3 specimen is 85% and 5% more than that of control specimen respectively. The beam specimens P1S, P2S series and P1G3 show a significant increase in post yield deflection when compared with control specimen. Similarly the beam specimens P1S, P2S series and P1G3 help to hold a peak load until a large deflection when compared with control specimen. The specimen P1S3 undergoes increase in load of 28% as compared to control specimen. The beam specimen with inclusion of steel fiber shows considerable improvement in the load carrying capacity as compared to the specimen with inclusion of glass fibers. During experimentation, it was observed that the specimen of P1S series allowed crack formation but the binding effect of steel fiber restricted its rate of growth. From the result it is observed that steel fiber carries the maximum flexural load due to the interior bond between the fiber and cement matrix. This interior bond delays the propagation of crack and sudden rupture of beam specimen which in turn increasing ductility behavior of steel fiber. On the other side, glass fiber has relatively lower effect on load deflection behavior of beam specimen. The lower effect of glass fiber on load deflection behavior is due to weaker bonding of glass fiber with the cement matrix as compared to steel fiber.

Conclusions

Fiber reinforced lightweight concrete mixes were prepared using lightweight coarse (pumice) aggregate, steel fiber and glass fiber. The mix P1 an P2 developed with 20% and 40% replacement of normal aggregate with pumice have the unit weight of 1985 kg/m^3 and 1820 kg/m^3 respectively. The mixes developed with the incorporation of glass and steel fibers have the unit weight ranging from 1830 kg/m^3 to 2200 kg/m^3. The unit weight of fiber reinforced lightweight concrete is lower compared to that of control concrete.

The compressive strength seems to increase with the inclusion of 0.5% of steel fibers in P1 mix with percentage increase of 3.8% as compared to control mix at 28 days. Inclusion of glass fiber has relatively lower effect on the compressive strength as compared to steel fiber.

The ductility of P1S3 and P1G3 beam specimen is 85% and 5% more than that of control specimen respectively. The beam specimens P1S1, P1S2, P1S3, P2S1, P2S1, P2S2, P2S3 and P1G3 show a significant increase in post yield deflection when compared with control specimen.

The beam specimens P1S1, P1S2, P1S3, P2S1, P2S1, P2S2, P2S3 and P1G3 help to hold a peak load until a large deflection when compared with control specimen. The beam specimen P1S3 undergoes increase in load of 28% as compared to control specimen.

From the results it is finally concluded that the loss of strength and ductility performance of LWAC can be compensated by the inclusion of fibers, without compromising much on the lightweight of the structure.

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