Flexural behaviour of High-performance concrete beams under Cyclic loading conditions

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ABSTRACT

Flexural behaviour of high-performance concrete (HPC) was affected by various parameters and plays a vital role in the strength of concrete. Present study aims in deciphering the role of cyclic loading on HPC reinforced with steel fibers. The study was carried out by casting of beams with hooked end steel fiber reinforced concrete with various grades (M60, M80, M100) and with admixtures (GGBS and Silica fume). Cast beams were studied for compressive strength, tensile strength, and flexural strength under cyclic loading. The study shows that there was a significant increase in compressive strength of HPC mixed with 1.0% of steel fiber. Flexural strength was found to be comparatively higher (upto 15% for all grades) for 1.25% steel fiber mixed HPC. Direct tensile strength is found to be higher than split tensile strength. Addition of steel fiber in HPC beam under cyclic loading, resulting in delayed or late development of cracks with decreased crack size.

Keywords: Mineral Admixtures, High performance concrete, Hooked-end Steel fiber, Cyclic loading, Direct Tensile test

INTRODUCTION

Demand for improved quality of concrete have paved way for various advancements in concrete technology including materials, mixture proportioning, recycling, structural design, durability requirements, testing, and specifications (Seabrook et al., 1984).Many studies have been carried out, in the past few decades, by various researchers, the properties like mechanical and durability improved when quality of the concrete is improved in service life and environmental aspects (Prajapati et al., 2017).In recent times research on High performance Concrete (HPC) have been carried out to address the improvement of specific property of concrete. High-Performance concrete (HPC) was used to meet the specific functional requirement of the concrete. To produce high-performance concrete, chemical and mineral admixtures are used along with an addition to basic ingredients that are used for normal concrete(Prajapati et al., 2017). Mineral Admixtures form an essential part of the High-Performance Concrete mix and are added to improve its mechanical and durability properties(Qureshi et al., 2020). In general, the packing characteristics of HPC are increased due to the addition of mineral admixtures.(Khan et al., 2014)On their review on mineral admixtures found the admixtures like Fly Ash, Silica Fume, Ground granulated Blast Furnace Slag, Metakaolin and Rice husk Ash affects the strength of concrete with their individual characteristics. Silica Fume (SF) and Ground Granulated Blast furnace slag (GGBS), due to their high pozzolanic character,have been used as admixtures in concrete(Halstead, 1986),(Abd Elrahman & Hillemeier, 2014). GGBS with particle size less than 45μm and rough texture possess cementitious and pozzolanic character; on the other hand, silica fume with particle size less than 0.1μm shows active pozzolanic character (Abd Elrahman & Hillemeier, 2014)The addition of silica fume and GGBS accelerates the concrete's secondary cementitious reaction, which leads to increases in strength. When calcium hydroxide reacted with silica, formation of tricalcium silicate takes place. The pozzolanic reaction may be represented as eq. (1) (Patel & Shah, 2013):

$$3Ca\,(OH)_2 + SiO_2 = 3CaO \cdot SiO_2 + 3H_2O \ldots\ldots\ldots\ldots (1)$$

The volume change in concrete was happening in plain concrete and similar brittle material will lead to the micro-crack before it undergoes loading, it was because of the drying shrinkage. The crack developed in the concrete beam can be arrested by the addition of steel fibers distribution in the concrete like closely spaced and dispersed uniformly and it will also improves the static and dynamic properties.The addition of steel fiber in to the concrete improves the flexural strength, ductility, bridging effect in crack development. On the negative side, it reduces the workability(Wang et al., 2008), which is overcome by adding water reducers into concrete.The coalescence and unstable growth developed in the concrete may be getting delayed in the presence of fiber in the concrete, it act as a bridge between the materials and act as a the stress transfer media.The performance of steel fiber in concrete depends on many factors such as type of steel fiber, shape, length, cross-section, tensile strength, fiber content, bond strength, matrix strength, mixed concrete composition and mixing in concrete.

The flexural properties of concrete composites are so important in the mix design and application of concrete composites(Wang et al., 2008). However, few studies have reported the effect of fiber (steel, polypropylene, natural fibers, etc.) and admixtures (like GGBS, SF, FA, RHA) on flexural strength and modulus of elasticity of concrete composites.The impact of cement and concrete blend on flexural strength is controlled by the factors like size of the member, nature of admixture, curing conditions, and concrete strength (Zhang et al., 2012). The steel fiber reinforced beams undergo large displacements without developing wider cracks compared to control beams. Both load and moment carrying capacity of steel fiber reinforced concrete were significantly increased. Strength of the concrete is reduced when it is subjected to cyclic load. It is reported that (Paul & Hussain, 2020)increasing reinforcement ratio decreases the interface damage resulting due to loading, decreases stiffness and also increases number of cyclic load that it can withstand. Beams in particularexhibits flexural failure when subjected to static loading,andwhen cyclic loading is applied, exhibit failure resulting due to damage of bonding between concrete and reinforcement. Influence of cyclic loadings that a structure can withstand/ support is controlled by the magnitude, cycles, and rate of loading that is applied on the structure(Elinwa& Kabir, 2019).Present study aims to address flexural strength of HPC prepared by using admixtures and steel fiber. Mechanical properties were carried out on conventional concrete and HPC. The study also aims to understand the effect of cyclic loading on flexural strength using hysteresis loop.

MATERIALS AND METHODS

HPC mix design carried out in accordance with ACI 211.9 as well as described by aitcin(Neville & Aïtcin, 1998). High performance concrete is produced by mixing ordinary Portland cement (OPC), M-sand as fine aggregate, the coarse aggregate of size 10 - 12.5mm, Silica fume & GGBS as mineral admixtures,hooked end steel fiber, and to improve workability,superplasticizers are used. The properties of materials used for this study are presented in Table 1.

Table 1 Properties of Materials used with standard values

S.No	Material	Properties	Result	Standard values	References
1	Portland cement (OPC)	Sp.Gravity	3.12	3.1 to 3.25	IS 12269-2013
		Initial setting time	45 min	>30 min	
		Final setting time	450 min	<600 min	
2	M-Sand (Zone- II)	Sp.Gravity	2.73	2.5 to 2.9	IS 383-2016
3	C.A(<12.5mm)	Sp.Gravity	2.87	2.5 to 3.0	
4	SF	Sp.Gravity	2.2	2.2 to 2.3	ACI 226-1988
5	GGBS	Sp.Gravity	2.87	2.8-3.1	IS 16714: 2018

The length of and diameter of hooked end steel fibers is 35 mm The diameter is 0.55 with an aspect ratio of is 64 is used. The Elastic modulus of the hooked end steel fiber is 200GPa. Silica fume and GGBS with size fractions of <0.1µm and 45µm respectively, were procured from commercial vendors for the present study. High range water reducers (Auromix 300) used in this study are of polycarboxylic ether base, with specific gravity of 2.2, poses capability of high dispersion of cement. The mixing of concrete is done with a pan mixer. The dry mix has been done for approximately 5 mins followed by addition of superplasticizer to the water; finally, fibers were added to the concrete with uniform dispersion of fibers. Steel fibers are added to the concrete on the basis of volume fraction as 0.25%, 0.5%, 0.75%,1%,1.25%, respectively. Servo computerized compression testing machine of 1000 kN was used to test the compressive strength of the cast cubes. Tensile strength of high-performance concrete was performed by two methods: Direct tensile test and Split tensile test. Cyclic loading tests for HPC were carried out using Self Straining loading frame of 400 kN capacity.

RESULT AND DISCUSSION

Compression test

The compressive strength was estimated for the cube specimen of size 100mm with different grades of concrete (M60, M80, M100) and fiber fractions (varying from 0.25% to 1.25%) at 7, 14, and 28 days. Compressive strength of M60-M100 with steel fibers detailed in figure 1-3. High compressive strength was achieved for fiber fraction of 1% in all the concrete grade M60, M80, M100, and a similar trend was observed (Lee et al., 2015).

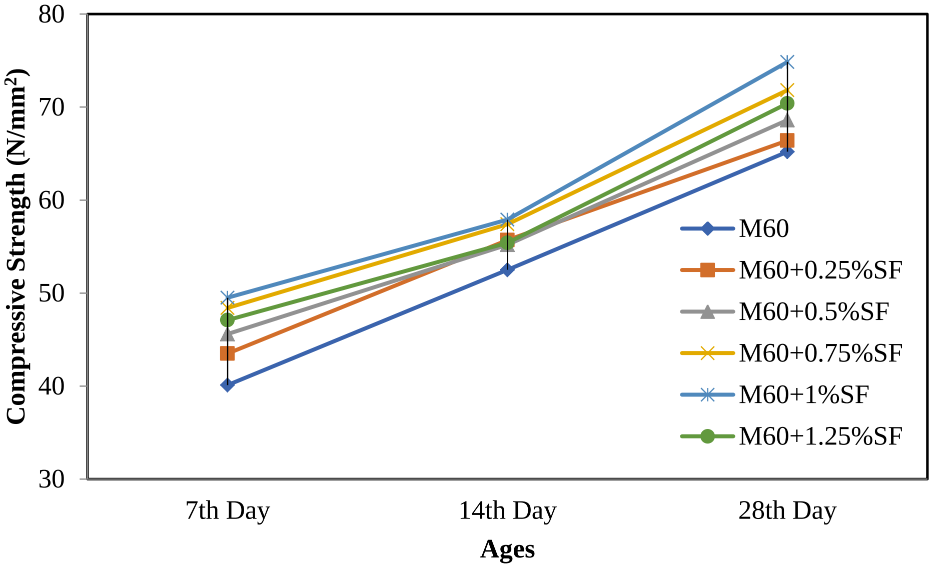

Figure 1 Compressive Strength of M60 with fiber Fractions

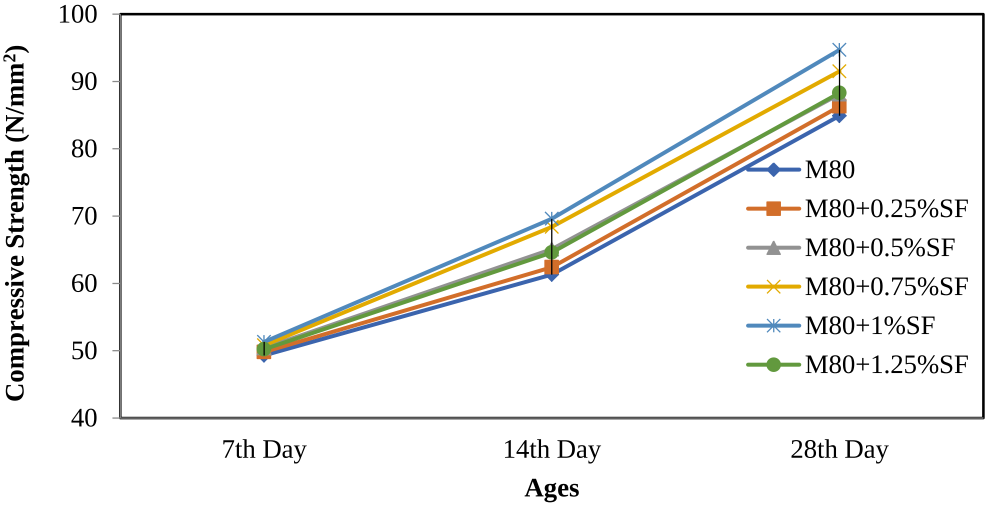

Figure 2 Compressive Strength of M80 with fiber Fractions

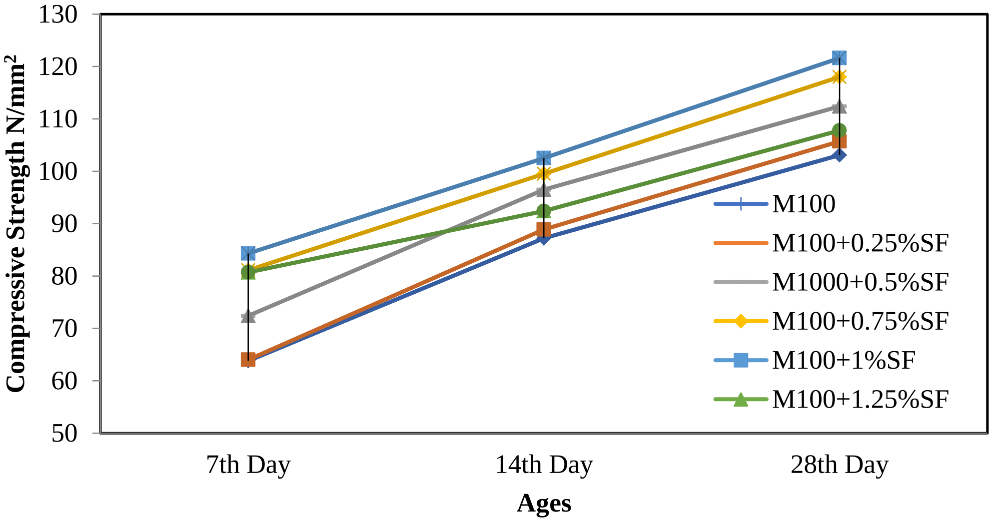

Figure 3 Compressive Strength of M100 with fiber Fractions

In M60 grade concrete, with the addition of 1% of steel fiber in volume fraction, the target strength increases by 25%.Likewise, for M80 and M100 the increment was 18% and 25% in target strength respectively. Compressive strength for fiber mix greater than 1% is observed to decrease due improper fiber dispersion that results in balling effect of concrete.

Tensile strength and Flexural strength of HPC

Tensile and flexural strength with different fiber fractions in different grades of concrete was studied and presented in table2. Direct tensile test of concrete was performed in concrete prism (dog bone shaped) specimen with a thickness of 75mm to investigate the direct tensile strength of concrete is shown in figure 5. The two ends of the concrete specimens (dog bone shaped) are anchored in the universal testing machine of 1000 kN capacity and tensile load was applied on the specimen (Fig. 5). The split tensile test was carried out in cylindrical concrete specimens that were placed in a horizontal direction, and load was applied over the concrete specimens. In the comparison (table 2), the direct tensile strength is lower than the split tensile strength of concrete, especially in HPC.The direct tensile strength results were more significant than split tensile strength test with variation of about 20% higher for direct tensile strength. The tensile strength increased by more than 100% for all the grades of concrete with the addition of 1.25% fiber fraction; a similar trend was observed (Ramkumar et al., 2020). The observed increase in direct tensile strength is due to the high yield property of fiber reinforced concrete as the effect is absent in split tensile strength where compressive action is predominant.

Table 2 : Tensile & flexural Strength of M60, M80, M100 with fiber fractions

Mix	Percentage replacement	Direct Tensile Strength (N/mm^2)	Split Tensile Strength (N/mm^2)	Flexural Strength (N/mm^2)
M60	0%	3.92	3.25	6.80
M60+0.25%SF	0.25%	4.15	4.01	7.20
M60+0.5%SF	0.50%	5.75	5.24	7.64
M60+0.75%SF	0.75%	6.25	5.37	8.21
M60+1%SF	1.00%	7.25	5.45	8.84
M60+1.25%SF	1.25%	8.12	6.43	9.13
M80	0%	4.92	4.56	7.54
M80+0.25%SF	0.25%	5.99	5.27	8.12
M80+0.5%SF	0.50%	7.54	6.57	8.78
M80+0.75%SF	0.75%	8.64	7.21	9.18

M80+1%SF	1.00%	9.21	7.54	9.56
M80+1.25%SF	1.25%	9.59	7.64	10.14
M100	0%	6.02	6.95	8.34
M100+0.25%SF	0.25%	7.54	7.33	8.83
M100+0.5%SF	0.50%	8.01	7.8	9.18
M100+0.75%SF	0.75%	8.54	8.14	9.76
M100+1%SF	1.00%	9.64	8.42	10.59
M100+1.25%SF	1.25%	10.72	8.59	11.16

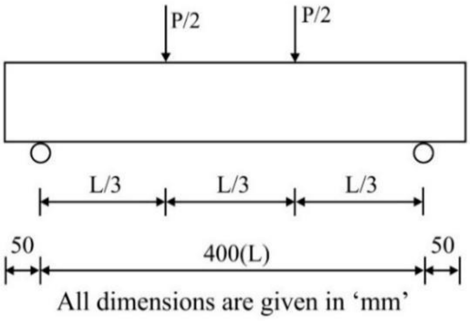

Figure 4 Flexural Specimen

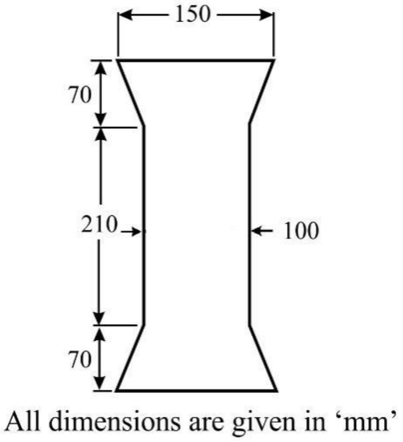

Figure 5 Direct tensile test Specimen

Figure 6 Direct tensile Experimental Setup

The flexural strength of HPC fiber concrete specimens was tested in the flexure specimen of size 100 x 100 x 500mm. The test was carried out under a four-point loading test, and all the flexural strength results were detailed in table 2. Flexural specimen shown in figure 4. The studied HPC's flexural strength shows an increase in strength at 1.25% (in volume) of fiber mixed in concrete compared to that of other fractions. Increase in flexural strength, which was maintained/ carried out only upto 1.25% as it was considered as optimal fiber content, was due to high yielding of concrete due to presence of steel fiber content. a 30% increase in flexural strength was observed for 1.25 % fiber fraction in all the concrete grades of M60, M80 and M100, a similar trend was observed(Halstead, 1986).

Cyclic loading of HPC

The half cyclic loading was applied in HPC specimen and increase in theloading rate was 2kN.Cyclic loading in HPC was increased in step wise basis with an increment of 2 kN and carried out for different cycles of 10 kN, 20 kN and so on till the maximum ultimate loading is reached. Upon reaching maximum load (10 kN, 20 kN …) the load was decreased at 2 kN interval till it reached zero. Residual strain/ deflection was considered for further cycles of the experimental process. The test setup and dimension details of the specimens are given in fig (7-16). Beams were strengthened with two 12mm reinforcement bars at bottom and two 10 mm reinforcement bars at top, 8 mm stirrups at 150 mm center to center spacing was provided. Those results were studied to understand the behavior of different grades of concrete.The hysteresis loop was drawn using deflection vs. load plot. It is observed that the first crack occurred in the normal beam nearly in the 2nd cycle and in the case of high-performance concrete beam, it occurred in the 3rd cycle. The deflection value was low in High performance concrete with fiber compared to normal high-performance concrete. Hysterisis loop (fig.14,16) shows that performance of HPC with fiber content showed significant improvement when compared with conventional HPC.

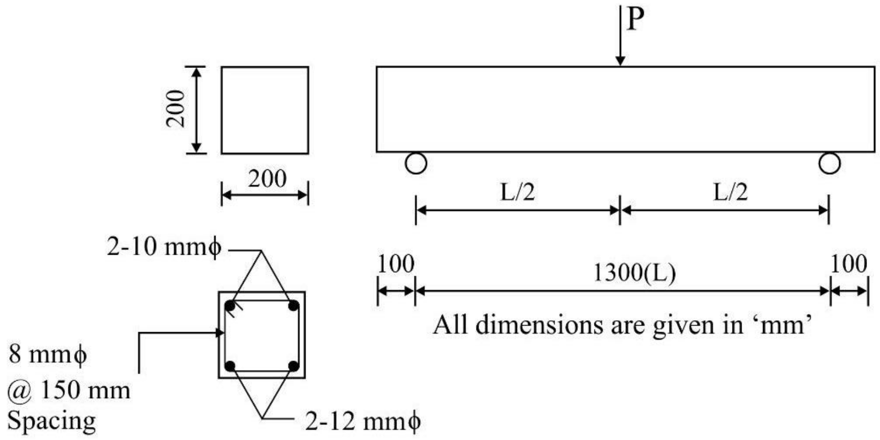

Figure 7 Details of cyclic loading on beams

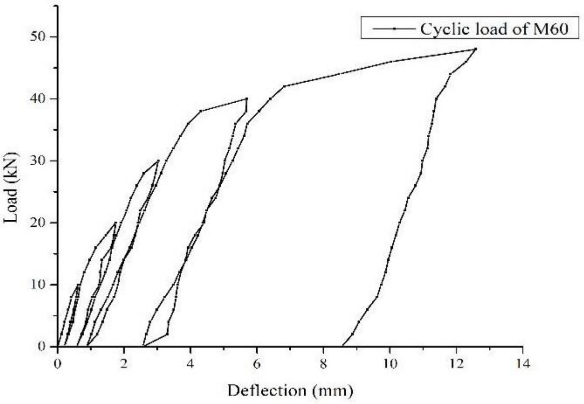

Figure 8 Cyclic Load curve for M60 grade of concrete

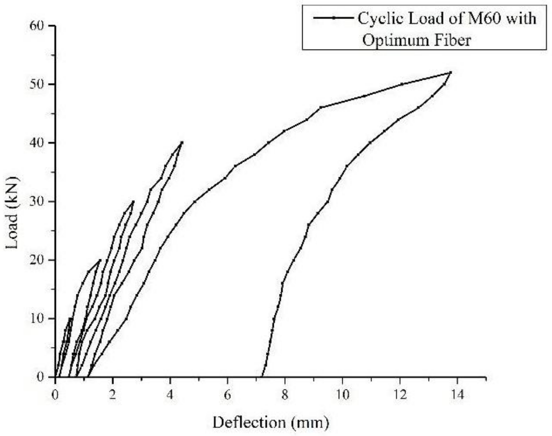

Figure 9 Cyclic Load curve for M60 grade of concrete with fiber

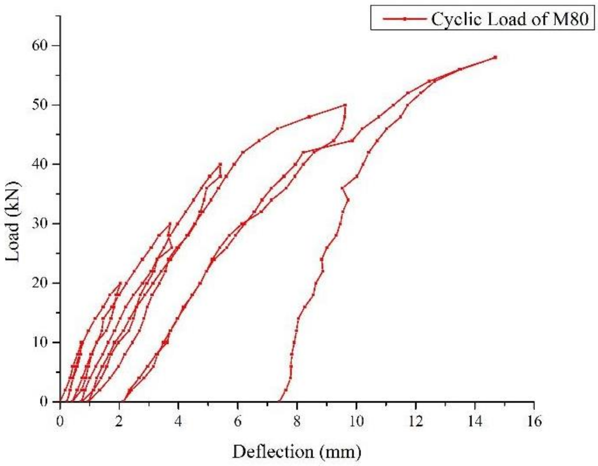

Figure 10 Cyclic Load curve for M80 grade of concrete

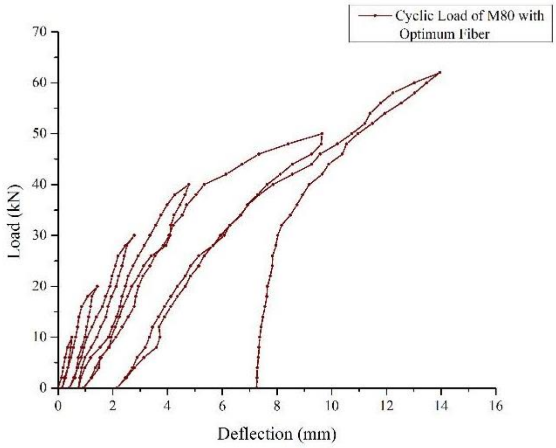

Figure 11 Cyclic Load curve for M80 grade of concrete with fiber

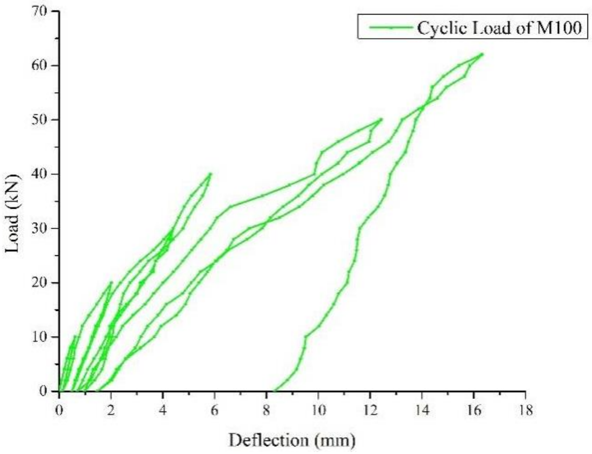

Figure 12 Cyclic Load curve for M100 grade of concrete

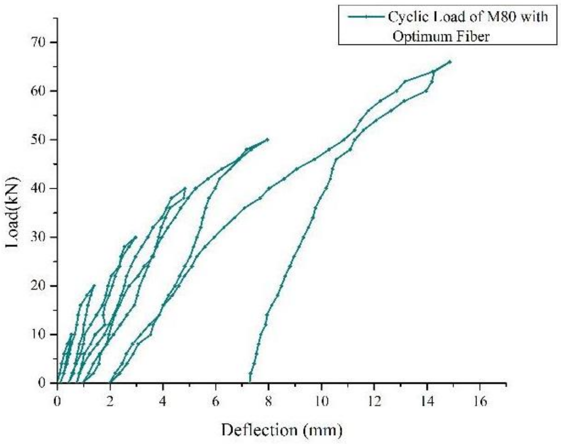

Figure 13 Cyclic Load curve for M80 grade of concrete with fiber

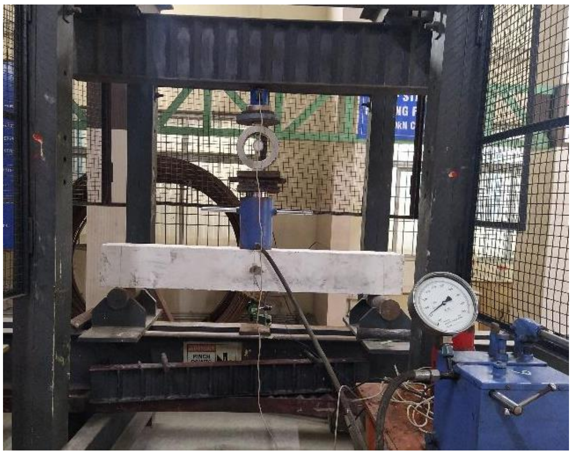

Figure 14 Experimental setup of Cyclic Load

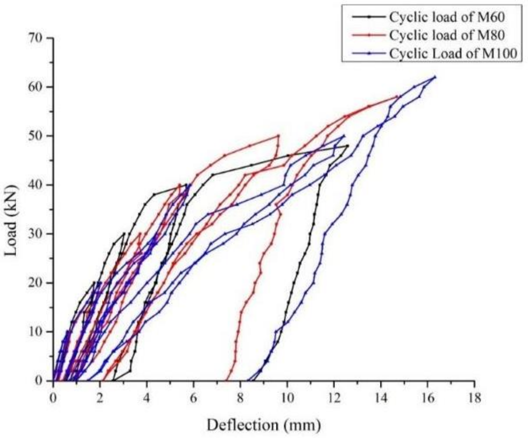

Figure 15 Cyclic Load curve for M60, M80,M100 grade of concrete

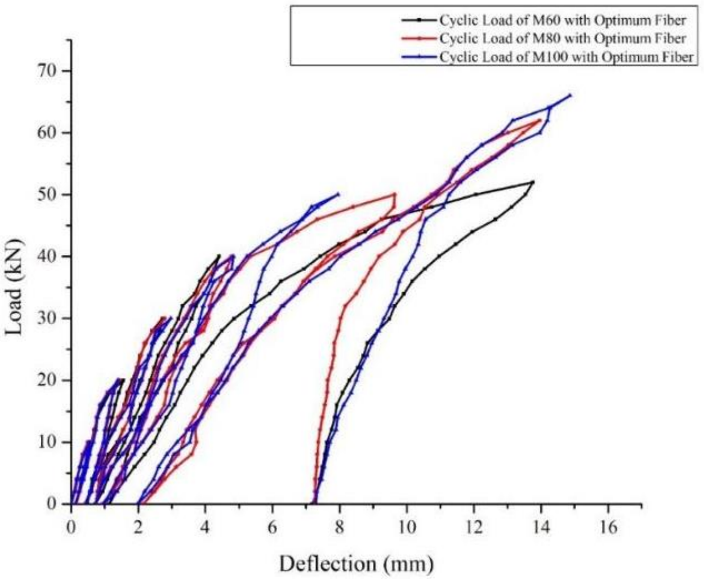

Figure 16 Cyclic Load curve for M60, M80, M100 grade of concrete with optimum Fiber

The hysteresis loop was wider for low grade conventional HPC whereas fiber mixed HPC showed a narrower loop indicating lower deflection; a similar trend was observed (Ganesan et al., 2014). The fiber mixed HPC beams showed greater dimensional stability which is evident from decrease in crack width and length.

CONCLUSION

Compressive strength of high performance concrete (HPC) was higher, with a minimum of 15% increase in strength, at 1% fiber mix concrete of all grades. On the ther hand flexural and tensile strength showed maximum strength at 1.25% fiber mix concrete. Percentage of increase in tensile and flexural strength at 1.25% fiber mix concrete is 30% and >100% respectively. Balling effect and improper dispersion of fibers plays a major role in decrease in strength of concrete mixed with higher firber fractions. High percentage (upto 20%) of high direct tensile strength compared to that of split tensile strength was observed due to high yielding of capacity of fibers. High performance concrete shows higher load carrying capacity under cyclic load condition under lesser strain rate. From the study it can be concluded that, at larger displacements, addition of steel fibers in HPC have resulted in high cyclic loading capacity without developing any large and wider cracks when compared with control beams.

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