International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-6, March 2020

Impact Response of Carbon Fiber Reinforced Concrete

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***Abstract*: Fiber reinforced concrete is becoming increasingly more important in the construction field due to its numerous applications and advantages. Fibre reinforced concrete (FRC) is composed of fibres and matrix. Fibres constitute the reinforcements and the main source of strength while the matrix 'glues' all the fibres together in shape and transfers the stress between the reinforcing fibres. Different types of fibres in use are steel, glass, carbon, basalt and aramid. Fibre reinforced concrete has many advantages such as improvement in the mechanical properties like modulus of elasticity, deflection, energy absorption and crack resistance.**

This paper discusses the experimental investigations carried out on carbon fiber reinforced concrete under impact loading. Mix design is carried out for M25 grade of concrete reinforced with carbon fibers in proportions of 0%, 0.75%, 1.00% and 1.25% by volume fraction. The test results show that there is an increase in compressive, split tensile and flexural strengths of carbon fiber reinforced concrete (not discussed in this paper). The inclusion of 1% carbon fibers showed the maximum enhancement in strength and it can be considered as optimum dosage. When compared to conventional concrete, the crack width also reduced in carbon fiber reinforced concrete. Extensometer test was conducted to determine the modulus of elasticity of concrete. The main aim of this study is to understand the dynamic behavior of carbon fiber reinforced concrete under impact loading. For carrying out the drop-weight tests, eight slab specimens were casted. The edges of the slab were fixed on all four sides. FRC slab with 1% addition of carbon fibres gave the best results. There was a decrease in displacement and an increase in impact energy for an the aspect ratio of fiber is 45.

***Keywords* : Fiber reinforced concrete, impact behavior, impact energy and modulus of elasticity**

I. INTRODUCTION

Civil engineering structures are subjected to many types of loads during their lifetime. Many structures undergo impact or dynamic loading. Dynamic loads from earthquakes or accidental vehicular collisions are usually considered by introducing an equivalent dynamic load factor. In conventional construction practice, compressive strength of concrete is often considered as an indicator of its quality. Impact loading has gained importance after the construction of nuclear power plants all over the world, as the structures are to be protected from bomb attack (Vinothini, 2012). Structures must possess greater resistance to impact loading to prevent collapse and minimize the damage to structures (Kiran, 2017).

Fiber reinforced concrete has unique advantages of corrosion resistance and high strength to weight ratio.

The modulus of elasticity of any material is essentially a measurement of the stiffness of a material against deformation. Deformation of a structure and modular ratio can be determined by determining the modulus of elasticity of concrete. Therefore, knowledge of modulus of elasticity of high strength concrete is very important in avoiding excessive deformation, providing satisfactory serviceability, and achieving the most cost-effective designs. (Misba Gul et.al. 2014))

II. METHODOLOGY

A. Materials used

The constituent materials used in this study are locally available Ordinary Portland Cement (O.P.C), M-sand and crushed granite. Potable water was used for mixing and curing. The tests were carried out as per IS Standards.BIRLA 53 grade ordinary Portland cement was used. Tests were conducted on cement as per IS 12269-1987 and cement used possessed a specific gravity of 3.10, fineness of 5%, normal consistency of 29%. The initial and final setting times of cement were obtained as 35 and 431 minutes. M-sand passing through 4.75mm IS Sieve was used as fine aggregate and crushed stone of size 20mm and 10mm down were used as coarse aggregates. The properties of fine and coarse aggregates used in the study are tabulated in Table I.

The superplasticer used in this study is Conplast SP430, a chloride free, superplasticising admixture based on selected sulphonated napthalene polymers. It is supplied as a brown solution which instantly disperses in water and gives good workability to fresh concrete.

The carbon fibers used for mixing is 12k (k signifies that there are 12000 filaments per 'tow' and is uni-directional. The properties of carbon fibres used are tabulated in Table II. Figure 1 shows the carbon fibers used for the present study.

B. Concrete mix design and proportioning

M25 grade concrete was designed as per IS 10262-2009.

Manuscript received on February 10, 2020.
Revised Manuscript received on February 20, 2020.
Manuscript published on March 30, 2020.

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Quantity of materials per cubic meter of concrete and dosages of carbon fibers used are listed in Table III. A constant water cement ratio of 0.48 was used.

Table I. Properties of M-sand and coarse aggregates tested as per IS 393-1970

Specification	Fine aggregate	Coarse aggregate	
		10mm	20mm
Specific gravity	2.60	2.72	2.70
Fineness modulus	2.88	3.77	5.23
Water absorption	6.6%	0.5%	0.5%

Table II: Properties of carbon fibers used in the study

Properties	Specifications/Dimensions
Color	Black
Length	20mm
Strain	2%
Fiber thickness	0.44mm
Tensile strength	4900MPa
Density	1790kg/m^3
Tensile modulus	250GPa

Table III: Quantity of materials used per cubic meter of concrete

Contents	Values (kg/m^3)
Cement	360.416
Fine aggregate	691.94
Coarse aggregate (20mm down)	770
Coarse aggregate (10mm down)	428
Water	173
Water cement ratio	0.48
Carbon fiber content	0.75%,1.00% and 1.25% (by volume of concrete)

C. Experimental investigations carried out

a. Fabrication of moulds

Cylindrical specimens of dimensions 10cm and 20cm were casted to determine the modulus of elasticity of concrete for carbon fiber reinforced concrete. For the impact tests, a total of eight slabs were casted out of which two were reinforced and out of the rest six slabs, two slabs each were casted for three varying percentages of carbon fibres. Slabs were casted for dimensions of 600 mm x 600 mm x 60 mm. and tested after 28 days of curing. To study the impact behavior of slab specimens the instruments used are discussed below.

i. Load cell:- A steel load cell of capacity 30T as shown in Figure 2 is used to measure the load vs time variation of each specimen.

Fig. 1 Carbon fibers used

Figure 2: Load Cell

ii. Linear Variable Different Transformer (LVDT) LVDT is an electrical transformer used to measure the displacement every minute. It was observed that the output is proportional to the displacement. The LVDT used in the present study is shown in Fig. 3.

Impact energy is a measure of the work done to fracture a test specimen. When the striker impacts the specimen, the specimen will absorb energy until it yields. At this point, the specimen will begin to undergo plastic deformation at the notch.

Figure 3: LVDT

Fig. 4: Impact Test Setup

Impact testing machine used in the present investigation is a drop weight machine fixed to a RCC pedestal foundation. The weight of hammer used is 10.2 kg. The slabs are placed on a square frame of size 600 x 600 mm and height of fall is maintained at 1m. Clamps are used along all the sides of slab to be fixed. One LVDT was placed at the center of slab and another at the corner of the slab. In general, the constant input energy is given by Equation 1,

$$E = wgh \tag{1}$$

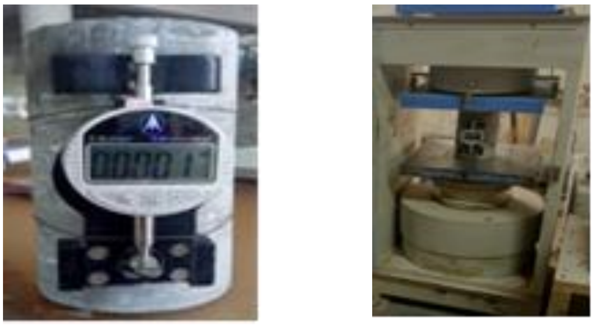

Fig 5. Extensometer mounted on the cylindrical specimen and the test set-up

where g denotes acceleration due to gravity, h is height of fall and w is weight of hammer. Load and displacements were measured using a data acquisition system. The tests were carried out till the slab specimens crack. Figure 4 shows the experimental setup of the impact testing machine used in this study.

C.1. Modulus of elasticity of concrete

An extensometer shown in Figure 5 was mounted on the cylinder of 10cm diameter and 20cm long as per IS 516-1959.The modulus of elasticity of plain concrete and carbon fiber reinforced concrete mix was based on 1% by volume fraction.

C.2. Data acquisition system (DAS)

The response of the test specimen is recorded by DAS consisting of hardware and software. A 12 bit A to D converter data acquisition system (DAS) is used.

A software in visual basic 6.0 is used to determine the different responses like load-time variation and displacement for all the slab specimens. The graphs are plotted in MS-Excel sheet..

III. RESULTS AND DISCUSSION

In this study, tests have been carried out to find the modulus of elasticity of concrete reinforced with 0% 0.75%, 1% and 1.25% carbon fibres. Impact test results have been used to plot the load vs time variation, peak load vs number of impact blows, displacement vs time variation, displacement vs number of impact blows and energy absorption curves and are presented in Figures. 8 to 13.

A.Modulus of elasticity of concrete

The modulus of elasticity of carbon fiber reinforced concrete was determined by subjecting the cylindrical specimen to uni-axial compression and an extensometer was used to measure the deformation. Secant modulus was determined using the slope i.e tan θ = stress/strain. The test results obtained from the extensometer test and from the standard formula involving characteristic strength of concrete are tabulated in Table IV. It is observed that the experimental and analytical results vary slightly. As tabulated in Table V, young's modulus of CFRC slabs increased in comparision to the plain concrete specimens.

Table V. Young's modulus of concrete for plain and fiber reinforced concrete

Percentage of carbon fibers	Extensometer (Young's modulus in GPa)	Young's modulus $5000\sqrt{fck}(MPa)$
0%	255.04	265.18
1.00%	345.53	335.41

B. Impact test

The slab specimen for the dimensions of 600mm x 600mm x 60mm is designed as a two-way slab. High yield strength deformed bars were used as reinforcement. Fig. 6 and Fig. 7 show LVDT placed at the center of slab and all the sides of slabs were fixed using c-clamps.

Fig 6: Placing of LVDT

C. Comparison of displacement vs time variations for un-reinforced concrete, reinforced concrete, CFRC slabs with 0.75%, 1% and 1.25% of carbon fibres

As observed from the displacement vs time variation for the concrete slab of displacement for the last blow is more as compared to that of the first blow. From the graph 8, the shape of pulse is found to be a triangle. From the theoretical studies and based on test results, the duration of pulse loading can be assumed as 50 millisec. It is observed that from displacement vs time curves, that the displacement increases with increase in number of impact blows.

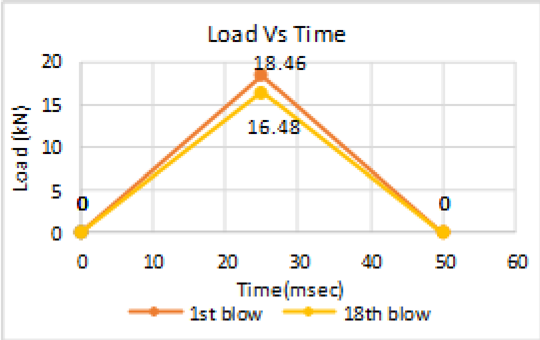

Figure 8a LVDT's (Linear variable differential transformer)

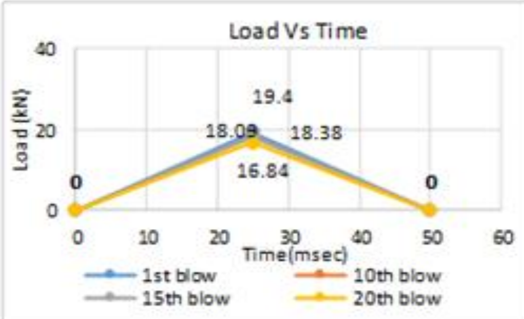

Figure 8b

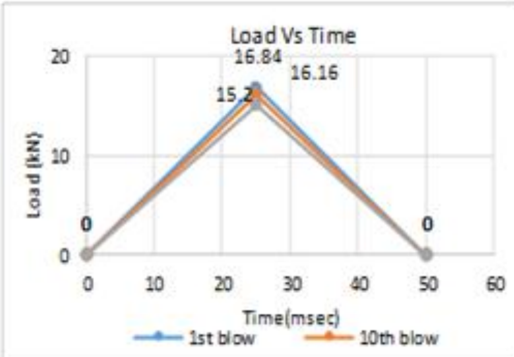

Figure 8c

Figure 8: Load Vs Time variation (a) for 0.75% for 1st and 18th blow and (b) 1.00% for 1st, 10th, 15th and 20th blow (c) Load Vs Time variation 1.25% for 1st, 10th and15th blow

The displacement vs time variation of slab specimens of 60mm thickness and M25 grade reinforced with carbon fibres of varying proportions are as shown in Figures 10 and 11 for the first and last blows.

D.Peak load vs Number of impact blows

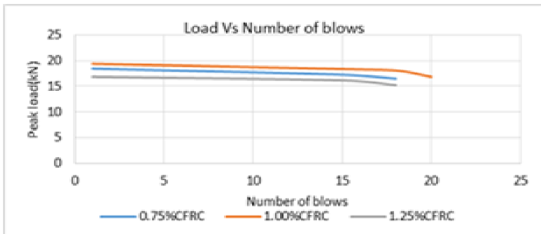

Figure 9: Peak load Vs Number of impact blows

Figure 9 shows the peak load for varying percentages of carbon fibers.

E. Displacement vs Time variation

Graph has been plotted for 0.75%, 1.00% and 1.25% addition of carbon fibres for which the load is applied till the 18th, 20th and 15th blow respectively.The displacements plotted are obtained at the mid-span of the slab.

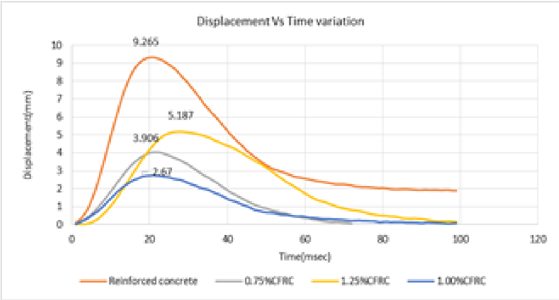

Fig 10: Displacement vs time variation for first blow for reinforced concrete, 0.75%, 1.00% and 1.25% of carbon fiber

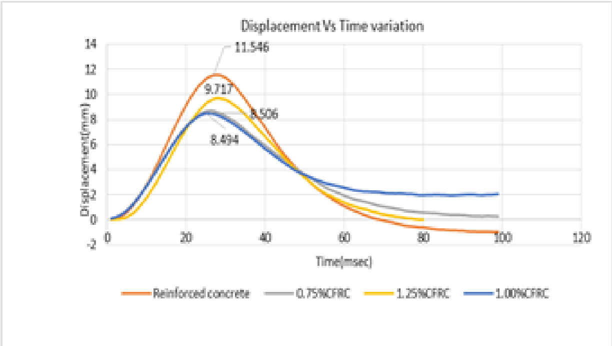

Fig 11: Displacement vs time variation for last blow for reinforced concrete, 0.75%, 1.00% and 1.25% of carbon fiber

The displacement is more for reinforced concrete as compared to the other percentage of carbon fibers, whereas for 1.25% of carbon fibers displacement is maximum among CFRC slabs. Figure 12 shows the displacement vs number of blows obtained at the midspan of the various slabs casted as reinforced concrete and using 0.75%, 1.00% and 1.25% of c carbon fibers.

F. Displacement –Number of impact blows

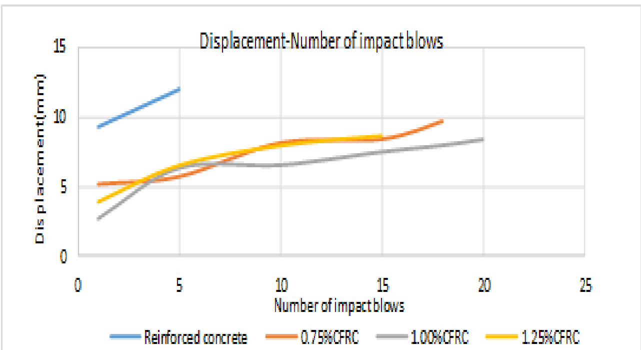

Figure 12: Displacement vs number of impact blows at mid-span of slab

G. Energy Absorption

Energy absorption explains the behavior of different fiber reinforced concrete specimens under repeated impact loading.

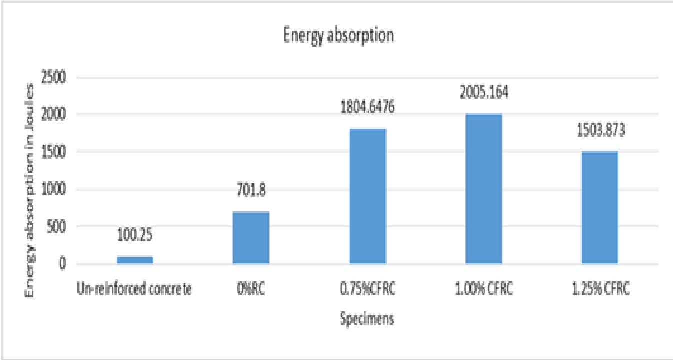

Figure 13: Energy absorption of un-reinforced concrete, 0%, 0.75%, 1.00% and 1.25% of carbon fibers

The energy absorbed by the different slabs- unreinforced, reinforced and CFRC slabs are shown in Figure 13.As seen in the graph, an addition of 1% carbon fibres enhances the energy absorption capacity of the slabs to the maximum.

III. CONCLUSIONS

The addition of carbon fibres upto 1% increases the the peak load of CFRC slab and any further addition reduces the peak load.

1. From the test results, it is observed that the peak load is maximum for 1.00% carbon fibres when compared to the 0.75% and 1.25% carbon fibres.

2. From the displacement vs time variation for first and last blows for reinforced concrete, 0.75%, 1.00% and 1.25% of carbon fibers, the maximum displacement is observed for reinforced slab followed by CFRC slabs with 1.25% carbon fibres.

3. When the load is applied at the center of the slab for all the slab specimens, the resistance of CFRC slab against impact loading increases up to an addition of 1% of carbon fibers and reduces for 1.25% carbon fibres.

4. From the displacement vs time variation graphs, it is observed that the displacement increases as the number of blows increases. The displacement increases to a certain extent with respect to time and then decreases. Compared to the other slabs, CFRC slab with 1% of fibres can take more number of impact blows.

5. There is an increase in impact energy by 65% for 1.00% of carbon fibers when compared to 0% , 0.75%, 1.25% carbon fibers and unreinforced slab.

6.The maximum percentage increase in compressive strength, Split-tensile strength and flexural strength was achieved at 1.0% of fibre dosage and was found to reduce for 1.25% of fibre content

7. The aspect ratio of fibers is 45 and 65% increase in impact energy for 1.00% of carbon fiber when compared with 0% of Carbon fiber.There is decrease in crack width for 1% carbon fiber. The reduction in crack width is directly proportional percentage of fiber added to concrete

Retrieval Number: F1213038620/2020©BEIESP
DOI:10.35940/ijrte.F1213.038620
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

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