IMPACT RESISTANCE OF STEEL FIBER REINFORCED CONCRETE

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Synopsis/ ABSTRACT

The present experimental investigation is to study the impact resistance of Fiber Reinforced Concrete with inclusion of steel fibers. The concrete composites comprises of steel fibers in different percentages. The hooked end type steel fibers varied from 0 to 2.5% at an interval of 0.5% by weight of cement. A simple economical and practical drop weight impact testing machine was used to determine the impact resistance for Steel Fiber Reinforced concrete [SFRC]. Impact test were carried out on SFRC with aspect ratio (l/d) as 60. The specimens were tested at 7 days and 28 days strength for concrete grade category like M20, M30 and M40. The specimens for impact studies were tested by drop weight Impact test method which was recommended by ACI-544 committee. The addition of steel fibers to concrete has improved the impact resistance considerably. The test results showed the variation of impact energy strength with different volume fraction of fibers.

Index terms/ keywords: *SFRC, impact energy, hooked end type steel fibers, drop weight impact testing apparatus, etc.*

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1. INTRODUCTION

Concrete is an intrinsically brittle material prone to damage through the impact of heavy items and loads particularly at exposed edges and arises. Impact damage is a major cause of a reduction in life span of any concrete construction, leading ultimately to early replacement.

Today, the structural Engineers are facing the problem of ensuring the safe structures which will withstand for the impact loads in addition to static loads. Many concrete structures are often subjected to short duration dynamic loads. These loads originate from sources such as impact from missiles and projectiles, wind gusts, earthquakes and machine vibrations. The need to accurately predict the structural response and reserve capacity under such loading had led researches to investigate the mechanical properties of component materials at such high rates of strain. Impact is a complex dynamic phenomenon involving crushing shear failure and tensile fracturing. The use of fibers was found to be advantageous in both static and impact conditions. Many investigators have shown that addition of fibers greatly increase the energy absorption and cracking resistance characteristics of concrete [1]. In the recent times, impact resistance of concrete is recognized as an important property in infrastructure construction. Several methods have been suggested by different guidelines that evaluate the impact resistance of FRC (ACI committee 544) such as Charpy test, projectile test, explosive test and drop weight test. Among them drop weight is simplest , popular and attractive method suggested by the ACI committee 544 [2].

Impact resistance is one of the important attributes of FRC. Conventionally, impact resistance has been characterized by measure of the number of blows in a “repeated impact” test to achieve a prescribed level of distress in the test specimen. Steel Fiber Reinforced Concrete [SFRC] promises good ductility and improved mechanical responses. The addition of Steel fibers to concrete improves the impact and fracture that are governed by toughness characteristics of concrete. In fact, Steel fibers bridge these cracks and restrain their widening and thus improve the post peak ductility and energy absorption capacity. Toughness can determined from the experimental and analytical evaluation. A repeated drop weight impact test (equipment and procedures) has been published by ACI committee 544. This reports yields number of blows required to cause a certain level of distress in fiber Reinforced concrete [FRC] specimen [3].

The objective of present work was to study the behavior of SFRC under impact loading with varied % of fibers. Impact energy was determined by using the simple and economical drop weight impact testing machine. The present experimental investigation is to study the impact resistance of FRC with addition of hooked end type of steel fibers in varying percentages like 0.5%, 1%, 1.5%, 2.0% and 2.5%.

2. EXPERIMENTAL PROGRAM

2.1 Material Properties

The cement used for concrete mixtures was 53 grade Ordinary Portland Cement confirming to IS 12269. The specific gravity of cement 3.15 was used for preparing the concrete mix of different grades. The impact behavior of SFRC was determined by drop weight impact testing machine as shown in **Figure-1.** Three different grades of concrete as M20, M30 and M40 were used with a inclusion of different percentages of Steel fibers. w/c ratio used in this investigation is as per IS design specifications. The specific gravities of the fine and coarse aggregates were 2.67 and 2.87 respectively. The maximum size of coarse aggregate was 20mm down. All the aggregates used were crushed limestone and their grading complied with IS:2386. High range water reducing admixtures complying with IS:9103 was used. Hooked end type Steel fibers with aspect ratio as 60 were used in this investigation. The length and diameter of hooked type Steel fibers were 30 mm and 0.5mm respectively.

2.2 Mixing Proportion

Mixture design was made in accordance with the Indian standard code IS 10262:1982 for M20, M30 and IS 10262:2009 for M40 grade of concrete. Concrete containing hooked end steel fibers were added to the mix in various proportions such as 0.5% to 2.5% at an interval of 0.5%. The workability of freshly mixed concrete was measured by Slump cone apparatus. The materials required for different grades of concrete were specified in **Table-1.**

2.3 Mixing Procedure And Specimen Molding

The mixing procedure was adopted on the basis of trial and error method. Trial mix is prepared as per the mixing proportions by the IS 10262 procedure, for different grades of concrete. The high range water reducer (super plasticizer) is used for mixing M40 grade of concrete. Slump cone apparatus were used to measure the workability of freshly mix concrete.

Freshly mix concrete was mixed using a tilting type mixer. Each trial mix of freshly mix concrete were casted in standard steel cube size 150x150x150 mm as per IS 516 standard procedure. Concrete mixes were being tested in a laboratory after 7 days and 28 days curing period at standard room temperature under compression testing machine.

2.4 Impact Test

The impact resistance of the specimens was determined in accordance with the procedure by ACI committee 544.2R-89. The impact test were conducted on 150mm(diameter) X 60mm(length) concrete cylindrical discs. The required standard specimen moulds are prepared by using PVC pipes and GI sheets**.** Six number of cylindrical disc specimens were tested to obtain average number of blows required to cause first crack and ultimate failure at 7 days and 28 days of curing. The impact load was applied with 135 N hammer instead of 44.5 N dropped repeatedly from a 290 mm height instead of 457 mm onto a 48 mm steel ball instead of 63.5 mm steel ball, which was located at the centre of the top surface of concrete disc. The Drop weight Impact testing machine developed as shown in **Figure-1.**

2.5 Impact Test Results and Discussion

Impact resistance of the specimen was determined at 28 days curing period. The number of blows resulting in the initiation of first crack and number of blows required for final fracture of plain concrete, as well as the fiber reinforced concrete with different volume fraction of fiber content and the impact resistance in terms of impact energy are shown in a table. From the results, it was noted that by using hooked end type steel fibers in the mixtures, there was considerably increase of number of blows needed for the first visible crack and fracture, when compared to plain concrete.

The impact energy delivered to the specimen produced by each blow is calculated as follows-

$$E_{I(Dynamic)} = \frac{1}{2} \times m \times (V_h)^2 \times N$$

Where

E_I – Impact energy(N-m)

m – drop hammer mass

V_h – impact speed(m/s)

N – number of blows at Ultimate failure

The impact energy absorbed by the specimen for each blow is calculated as follows-

$$E_{I(Static)} = m \times g \times H \times N$$

Where

E_I – Impact energy(N-m)

m – drop hammer mass

H – height of drop mass

N – number of blows at Ultimate failure

V_h=gt……………………………………i)

m=(W/g)…………………………………ii)

H=(gt^2/2)………………………………...iii)

Substituting the corresponding values in above equations

$290 = (9810 \times t^2) / 2$

t = 0.1937 sec ;

$V_h = 9810 \times 0.1937 = 1899.92$ mm/s

The Impact energy delivered by hammer per blow can be obtained by using equation as below$E_{I(Dynamic)} = \frac{1}{2} \times m \times (V_h)^2 \times N$

$= (135 \times 1899.92^2) / (2 \times 9810)$

= 24.83 kN mm

3. RESULTS AND DISCUSSIONS

By addition of hooked end type steel fibers at 0.5%, 1.0%, 1.5%, 2.0% and 2.5%, it was observed from the tabular results and graphical variation that the impact energy required to cause the visibility of the first crack and failure of concrete specimen were not differentiated considerably. The impact energy required to cause the complete failure of concrete specimen by addition of hooked end type steel fibers at 0.5%, 1.5% and 2.5% was increased by149%, 200% and 300% respectively.

From the tabular results through **Table-2, Table-4 and Table-6**, it was experimentally observed that the variation static and dynamic impact energy for M20, M30 and M40 concrete grade at 0.5%, 1.5% and 2.5% of volume fraction fibers were increased by 151% .

From the tabular results through **Table-3, Table-5 and Table-7** and graphical variation through **Figure- 4 and Figure- 5,** the variation of maximum static impact energy and dynamic impact energy at the ultimate failure of test specimen were shown.

From the graphical variation through **Figure-2 and Figure-3** for M20, M30 and M40 grade concrete, the number of blows required to cause first crack and complete failure of concrete specimens were increased considerably with the addition of steel fibers.

4. CONCLUSIONS

Based on experimental results, the following conclusions are drawn.

- It was found that increase in volume of steel fibers leads to increase in impact resistance.
- The impact resistance also increased against the first visible crack and final fracture, which means that the energy absorption capacity in concrete with steel fibers increased.
- By incorporation steel fibers to the concrete, the failure mode was changed from brittle to ductile behavior, which displays the beneficial effects of FRC, used in structural Engineering applications.

NOTATION:

* Indicates that the test sample at max. impact energy for particular volume fraction
Sp – denotes as super plasticizer.
W/B – water to binder ratio
FA – fine Aggregates test sample
CA – coarse aggregate test sample.
E_I – Impact energy(N-m)
m – drop hammer mass
H – height of drop mass
N – number of blows at Ultimate failure
SFRC – Steel Fiber Reinforced Concrete

Table-1: mixing proportions for 1 m^3 concrete mix.

Sr. No	Specimen identification	FiberVolume fraction(%)	Impact resistance (No of blows)		Impact energy (N-m)	Impact energy (N-m)
			First crack	Ultimate failure	Dynamic	Static
1	M20-1	0.0	1	2	49.66	76.81
2*	M20-2	0.0	2	2	49.66	76.81
3	M20-3	0.0	1	2	49.66	76.81
4	M20-4	0.5	2	2	49.66	76.81
5	M20-5	0.5	2	3	74.49	76.81
6*	M20-6	0.5	2	3	74.49	115.23
7	M20-7	1.0	2	3	74.49	115.23
8	M20-8	1.0	2	4	99.32	153.62
9*	M20-9	1.0	3	4	99.32	153.62
10	M20-10	1.5	3	5	124.15	192.03
11*	M20-11	1.5	3	4	99.32	153.62
12	M20-12	1.5	3	5	124.15	192.03
13	M20-13	2.0	3	5	124.15	192.03
14	M20-14	2.0	4	6	148.98	230.43
15*	M20-15	2.0	4	6	148.98	230.43
16	M20-16	2.5	4	5	124.15	192.03
17	M20-17	2.5	3	5	124.15	192.03
18*	M20-18	2.5	3	6	148.98	230.43

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Table-2: Test Sample Grade M20

Sr. No	Concrete Grade	W/B	Water (Kg/m^3)	Cement (Kg/m^3)	FA (Kg/m^3)	CA (Kg/m^3)	Slump (mm)	SP	Mix. C:FA:CA
1	M-20	0.52	191.5	368	545	1159.2	25-50	nil	1:1.48:3.15
2	M-30	0.44	189	429.5	567	1245.55	25-50	nil	1:1.32:2.9
3	M-40	0.32	157.6	492.5	586	1280.5	75-100	Sp-430	1:1.18:2.6

Table-3. Test Sample at max. Impact energy M-20 Grade

Sr. No	Mix Name	Fiber Volume fraction(%)	Impact resistance (No of blows)		Impact energy (N-m)	Impact energy (N-m)
			First crack	Ultimate failure	Dynamic	Static
1	M20-2	0.0	2	2	49.66	76.81
2	M20-6	0.5	2	3	74.49	115.23
3	M20-9	1.0	3	4	99.32	153.62
4	M20-11	1.5	3	4	99.32	153.62
5	M20-15	2.0	4	6	148.98	230.43
6	M20-18	2.5	3	6	148.98	230.43

Table-4: Test Sample Grade M30

Sr. No	Specimen identification	Fiber Volume fraction (%)	Impact resistance (No of blows)		Impact energy (N-m)	Impact energy (N-m)
			First crack	Ultimate failure	Dynamic	Static
1	M30-1	0.0	2	3	74.49	115.23
2	M30-2	0.0	2	4	99.32	153.62
3*	M30-3	0.0	3	5	124.15	192.03
4	M30-4	0.5	3	4	99.32	153.62
5	M30-5	0.5	2	3	74.49	115.23
6*	M30-6	0.5	3	5	124.15	192.03
7	M30-7	1.0	3	6	148.98	230.43
8*	M30-8	1.0	4	6	148.98	230.43
9	M30-9	1.0	3	5	124.15	192.03
10	M30-10	1.5	4	5	124.15	192.03
11*	M30-11	1.5	4	6	148.98	192.03
12	M30-12	1.5	4	6	148.98	192.03
13	M30-13	2.0	3	6	148.98	192.03
14	M30-14	2.0	4	6	148.98	192.03
15*	M30-15	2.0	4	7	173.81	268.84
16	M30-16	2.5	5	6	148.98	192.03
17	M30-17	2.5	4	7	173.81	268.84
18*	M30-18	2.5	5	7	173.81	268.84

Table-5. Test Sample at max. Impact energy M-30 Grade

Sr. No	Mix Name	Fiber Volume fraction (%)	Impact resistance (No of blows)		Impact energy (N-m)	Impact energy (N-m)
			First crack	Ultimate failure	Dynamic	Static
1	M30-3	0.0	3	5	124.15	192.03
2	M30-6	0.5	3	5	124.15	192.03

3	M30-8	1.0	4	6	148.98	230.43
4	M30-11	1.5	4	6	148.98	230.43
5	M30-15	2.0	4	7	173.81	268.84
6	M30-16	2.5	5	7	173.81	268.84

Table- 6: Test Sample Grade M40

Sr. No	Specimen identification	Fiber Volume fraction (%)	Impact resistance (No of blows)		Impact energy (N-m)	Impact energy (N-m)
			First crack	Ultimate failure	Dynamic	Static
1*	M40-1	0.0	3	5	124.71	192.03
2	M40-2	0.0	4	5	124.71	192.03
3	M40-3	0.0	4	5	124.71	192.03
4*	M40-4	0.5	5	7	173.81	268.84
5	M40-5	0.5	4	6	148.98	230.43
6	M40-6	0.5	4	5	124.15	192.03
7	M40-7	1.0	5	7	173.81	268.84
8*	M40-8	1.0	5	7	173.81	268.84
9	M40-9	1.0	5	7	173.81	268.84
10	M40-10	1.5	4	6	148.98	230.43
11*	M40-11	1.5	5	8	198.64	307.25
12	M40-12	1.5	5	7	173.81	268.84
13	M40-13	2.0	4	7	173.81	268.84
14*	M40-14	2.0	6	9	223.47	345.65
15	M40-15	2.0	4	6	148.98	230.44
16*	M40-16	2.5	6	10	248.30	384.06
17	M40-17	2.5	5	9	223.47	345.65
18	M40-18	2.5	5	8	198.64	307.25

Table-7. Test Sample at max. Impact energy M-40 Grade

Sr. No	Mix Name	Fiber Volume fraction(%)	Impact resistance (No of blows)		Impact energy (N-m)	Impact energy (N-m)
			First crack	Ultimate failure	Dynamic	Static
1	M40-1	0.0	4	5	124.15	192.03
2	M40-4	0.5	5	7	173.81	268.84
3	M40-8	1.0	5	7	173.81	268.84
4	M40-11	1.5	5	8	198.64	307.25
5	M40-14	2.0	6	9	223.47	345.65
6	M40-16	2.5	6	10	248.3	384.06

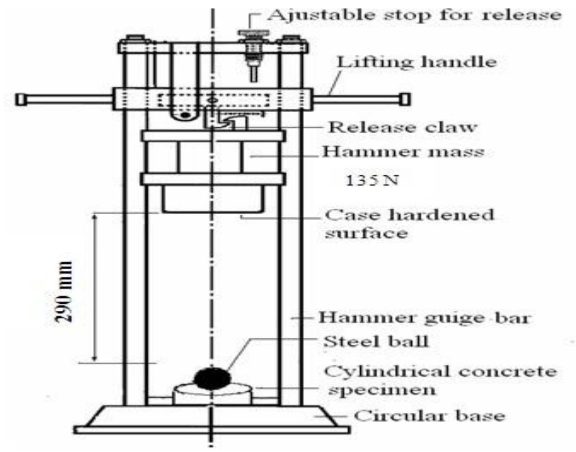

Figure-1. Schematic diagram of drop weight impact testing machine

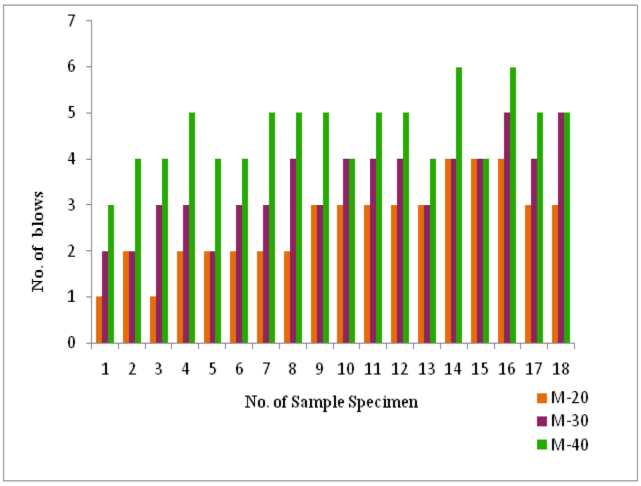

Figure-2: M20, M30 and M40 concrete Grade with no. of blows at First crack

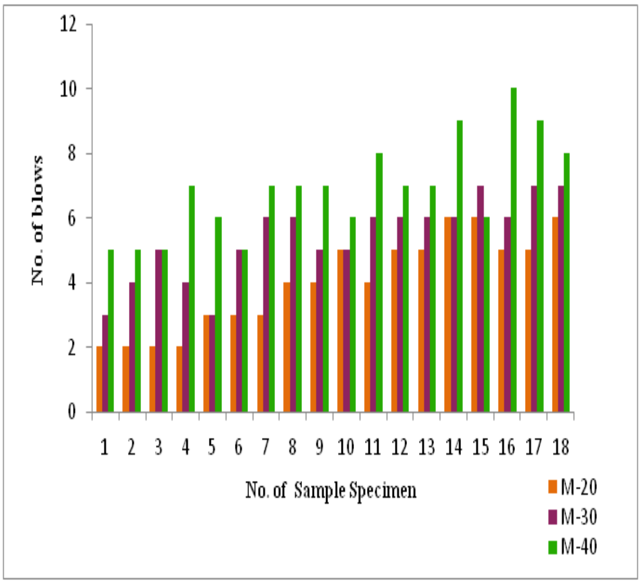

Figure-3: M20, M30 and M40 concrete Grade with no. of blows at ultimate failure

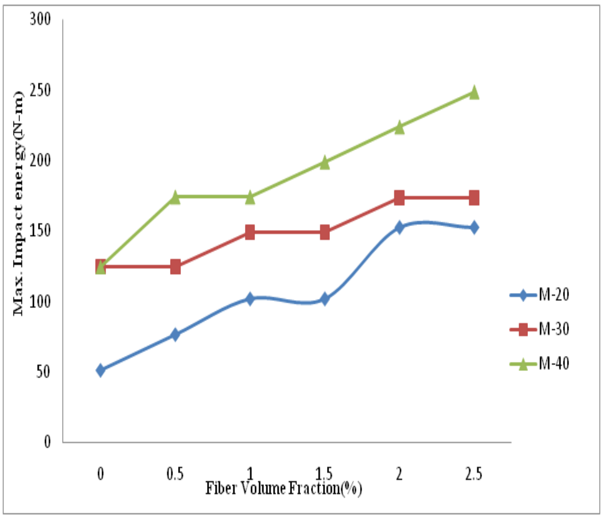

Figure -4 Grade M20, M30 and M40 concrete mix comparison with Dynamic Impact Energy

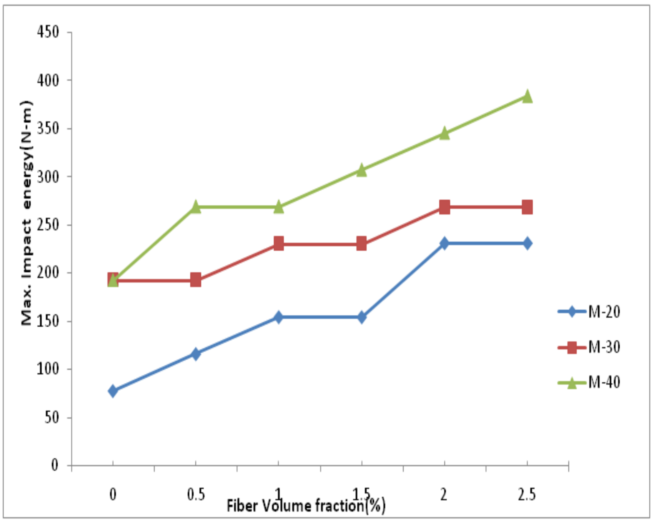

Figure -5 Grade M20, M30 and M40 concrete mix comparison with static Impact Energy