A COMPLETE MECHANICAL CHARACTERIZATION OF A HIGH STRENGTH GLASS FIBER REINFORCED CONCRETE BY WEIBULL ANALYSIS

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The study of High strength concrete with fibers had become the most popular topic as the demand for height and load carrying capacity of every infrastructure is increasing. The addition of fibers in concrete increases durability, tensile strength, toughness, energy absorption, high impact resistance, in terms of both static and dynamic loading. In this paper, the strength properties of glass fiber reinforced concrete as a structural element was investigated. Different ratios of GFRC mixes were designed, cast, tested, and compared with the results of compressive strength, tensile strength, flexural strength, and also impact strength.M50 grade of concrete was used in this study with five proportions (0, 0.5%, 1%, 1.5%, 2%) of Glass fibers. The impact strength test was analyzed using Weibull analysis to compare with the experimental data. The main objective of this study is to show how the increase in fibre percentage increased the strength of concrete.

Keywords: *Glass Fiber, High Strength Concrete, impact strength, Weibull method, Numerical analysis, Strength Properties.*

1. Introduction

The glass fiber, initially used as an insulation material, was invented in 1938.Glass fibers technically show high strength and alkali resistance while mixing it with concrete [1]. The main load-carrying member of concrete is the fibers and other members keep the fibers in their correct position, correct direction and also protect the fibers from getting damaged [19]. Glass fiber consists of 150-450 individual filaments which are put together or bonded lightly to form a strand. These strands are then cut down into the required length. Most of the applications using glass fiber reinforced composites are in the shape of a laminate [2]. Glass fiber is usually light in weight [22] i.e. about one-third of conventional concrete [3]. Even though it is light in weight it attains good tensile as well as flexural strength [4]. The GFRC can be molded into any shape with ease, as a result of which it is used as decorative columns, decorative panels, and architectural precast concrete [17].

1.1. Types of fiber

There are many fibers present in the world [5]. Out of which, some of the well-known fibers are Steel, Asbestos, polypropylene, natural or organic, carbon, etc[6,]. In the present day, fiber technology is increasing at a rapid speed [7].

1.2. C*lassifications in glass fiber*

See table at the end of the page.

2. Materials which are used in current study

The properties of materials used in the study are listed as follows.

2.1. Cement

The cement that has been used in the study is 53 Grade ordinary Portland cement [12] confirming to Indian standard IS 12269-2013. The chemical as well as physical properties are shown in Table 1.

2.2. Fine aggregate

River sand is used as a fine aggregate. The fine aggregate conforming to zone II of IS: 383 is used. The river sand obtained in single consignment was sieved as per IS sieves as per in Table 2. The specific gravity of sand is 2.64. The fineness modulus is 2.86.

2.3. Coarse aggregate

Crushed angular granite metal aggregate from local sources is used in the present study. The size of the aggregate used study is 12.5mm. The coarse aggregates used conforms to IS code specifications IS 383:2016, IS 2386:1963. The specific gravity of coarse aggregate is 2.81.

Type	Description	Nature
A	Alkaline-lime with less quantity of boron [8]	Not resistance to alkaline nature
C	Alkaline-lime with some quantity of boron	Resistance to chemical attack
D	Composition with borosilicate [9]	Has high dielectric constant
E	Contains alumino-borosilicate	Not resistance to chloride-ion
AR	Alkali resistance glass [10]	Highly resistant to alkaline nature
R	Aluminosilicate without (magnesium or calcium) oxide [11]	Shows good mechanical property
S	Aluminosilicate with magnesium oxide, without calcium oxide	High tensile strength

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Table 1

Chemical and physical properties of Cement

Particulars	Experimental outcomes	Standard values as per IS 12269-2013
Chemical Properties		
Tri-calcium Silicate (C_3S) (%)	45.35	-
Di-calcium Silicate (C_2S) (%)	27.1	-
Tri-calcium Aluminate (C_3A) (%)	7.02	-
Tetra-calcium Alumino ferrate (C_4AF) (%)	13.4	-
Alumina Iron Ratio (A1203 / Fe503) (%)	1.11	0.66Min
Insoluble Residue (% by mass)	2.37	3.00Max
Magnesia (MgO)(% by mass)	1.06	6.00Max
Sulphur Anhydride (% by mass)	2.60	3.00Max
Total Loss on Ignition (% by mass)	2.73	4.00Max
Total Chlorides (% by mass)	0.009	0.10Max
Physical Properties		
Fineness (Specific surface) (m^2/kg)	286	225Min
Specific gravity	3.15	-
Normal Consistency (%)	32.67	28 to 33
Setting time (Minutes)		
a. Initial	60	30Min
b. Final	155	600Max
Compressive strength (MPa)		
a. 3 days	29.40	27.0Min
b. 7 days	39.33	37.0Min
c. 28 days	57.64	53.0Min

Table 2

Particle size distribution for fine aggregate (1000g)

Sieve size(mm)	Mass of sand retained (g)	Percentage mass retained	Cumulative percentage mass retained	Percentage passing
4.75	82	8.2	8.2	91.8
2.36	76	7.6	15.8	84.2
1.18	146	14.6	30.4	69.6
.6	295	29.5	59.9	40.1
.3	256	25.6	85.5	14.5
.15	76	7.6	93.1	6.9
.075	62	6.2	99.3	0.7
Pan	7	.7	100	0

Table 3

Chemical and physical properties of fly ash

Particulars	Experimental test results
Chemical Properties	
SiO_2	55.50
Al_2O_3	18.46
Fe_2O_3	6.71
CaO	8.58
MgO	1.93
Na_2O	0.59
K_2O	0.85
SO_3	.21
Physical Properties	
Specific surface (cm^2/g)	2470
Specific gravity	2.16

2.4. Fly ash

The fly ash used in the current study conforms to IS 3812:2013. The chemical and physical properties of fly ash are as given in Table 3. The cement is replaced by 10% by the use of fly ash in the mix proportions and volume fractions.

2.5. Silica fume

The silica fume used is purchased from silicon and ferrosilicon metal factories [23]. These have stable SiO_2 content of this product ranges from 85% to 95%. The silica fume used meets the requirements of ASTM and contains a minimum of

Table 4

Chemical and physical properties of silica fume

Particulars	Experimental test results
Chemical Properties	
SiO_2	93.72
Al_2O_3	0.82
Fe_2O_3	0.42
CaO	0.34
MgO	1.44
Na_2O	0.4
K_2O	1.22
SO_3	0.47
Physical Properties	
Specific surface (cm^2/g)	-
Specific gravity	2.3

Table 5

Properties of Glass Fiber

Type of glass fiber	AR glass fiber
Specific gravity (g/cm^3)	2.7
Filament diameter	13, 19microns
Tensile strength (MPa)	1700
Modulus of elasticity (E)(GPa)	72
Chop length (mm)	6, 12
Aspect ratio	860.4
Filaments per kg	210 million fibers
Elongation at failure (%)	-3.5
Zro3 content	17%
Moisture content	<.5%(max)
Incombustibility	Yes
Resistance to acid	Yes
Electrical conductivity	Very low
Chemical resistance	Very high
Strain to failure	2%

Table 6

Quantities of materials required per 1cum of concrete

Mix ingredients	Quantity (in Kg.)
Cement	389.18
Fine aggregates	626.20
Coarse aggregate	1100
Water	180
Fly ash	48.65
Silica fume	64.58
Super plasticizer (SP340)	0.00162(1%)

88% silicon dioxide [18]. The chemical and physical properties are as in Table 4.

2.6. Water

For purposes such as curing and mixing water is used. Water should be clean and free from injurious quantities of alkalis, acids, oils, salts, sugars, organic materials, and other materials that adhere in strength gaining property of brick, stone, concrete, or steel [24]. The PH value of water should not be less than 5.6.

2.7. Glass fiber

Cem-FIL Anti-crack HD glass fibers are used. The glass fibers used are alkaline resistant and are water dispersed. The specifications are as in Table 5.

2.8. Mix design

The complete M50 mix design for the specimen was found out using various trial and error methods. Later one final mix design was found out as given in Table 6.

2.9. Casting of specimens

In this research, a total of 64 specimens of various shapes were cast such as cube (100x100x100mm), cylinder (100mm diameter and 200mm height), beam (500x100x100mm), and 200 specimens of the disc (150mm diameter and 650mm height). To cast specimens all, the materials were assembled in the workplace. Then materials were batched and mixed according to the requirements. In the control mix, no (0%) fiber
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Table7

Cube Compressive strength in MPa

No. of days	**Glass Fiber dosage**				
	0%	0.5%	1%	1.5%	2%
3 days	22.34	18.98	24.77	25	24.56
7 days	38.92	36.56	39.56	41.52	40.23
14 days	49.88	47.76	49.69	51	50.30
28 days	54.64	50.78	52.16	58.89	53.67
56 days	58.23	54.97	55.58	60.50	59.34

is added. In preceding mixes, fiber content is increased by 0.5%. To ensure uniformity in the mixture all the materials are hand mixed [25]. The fine and coarse aggregate was first taken and mixed for 1 minute, and then binders- cement, silica fume, and fly ash were added and mixed properly for 2 minutes. Then water reducing agent (superplasticizer) [20] and water were added and mixed uniformly for 3 minutes. The distribution of fly ash, silica fume, and fibers have a greater effect on the workability and water impermeability of concrete mixture [30-32].

After the preparation of fresh concrete, it has been tested for workability test. The workability of fresh concrete is evaluated based on the slump and slump flow in the slump cone test.

After the slump cone test, the prepared concrete is placed into the molds. After sufficient time for hardening, the specimens were removed from molds and placed in a curing tank. Care is taken to properly cure the concrete, to achieve the best strength and hardness. This happens after the concrete is placed for curing. Concrete requires a moist, controlled environment to gain strength and harden fully. The concrete hardens over time, initially setting and becoming rigid though every week and gaining strength in the following weeks.

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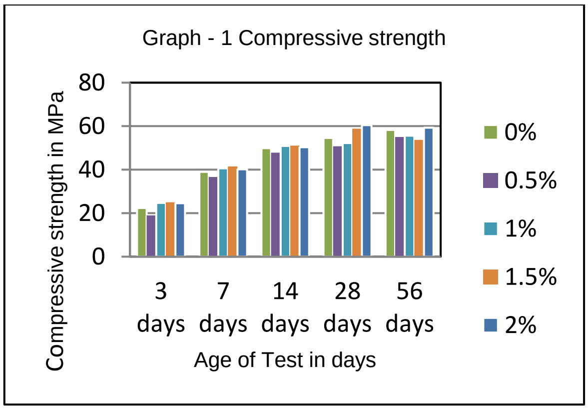
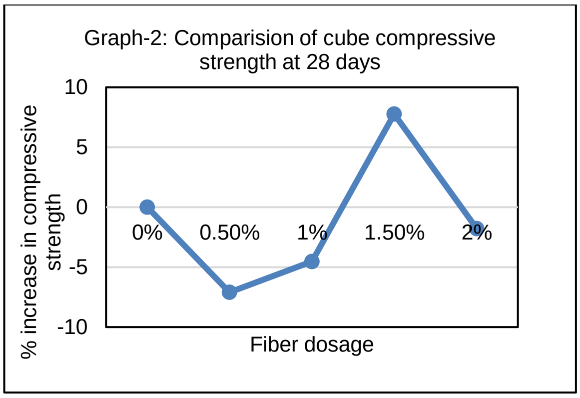
3. Test results and discussions

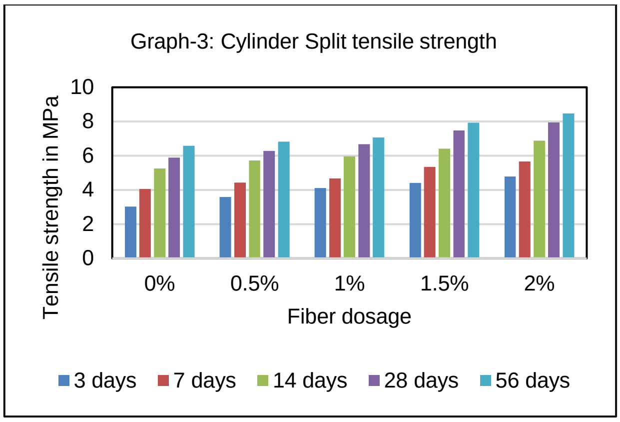
3.1. Compressive strength

The effect of adding glass-reinforced fiber in different ratios on the compressive strength of concrete is studied by testing cubes of 100x100x100mm. The cube compressive strength with a 0.5% increase of fiber content is shown in Table - 7. As the days pass, we can observe that there is an increase in compressive strength. The compressive strength at 28 days for 0%, 0.5%, 1%, 1.5%, 2% addition of fiber content is 54.64, 50.78, 52.16, 58.89, and 53.67 respectively. We can say that there is a decrease in compressive strength when .5%, 1%, 2% fiber dosage is added to specimens when compared to the control mix (0% fiber dosage specimen). Whereas we can also observe that there is an increase in compressive strength when 1.5% fiber content is added to the mix. This % increase or decrease in compressive strength concerning the control mix (0% fiber content mix) is shown in the Graph1,2.

In the study, fiber addition is restricted to 2% because of the further increase in fiber content results in disturbance to attain the homogenous mixture. Generally, the addition of fiber content greater than 2% results in clusters, fiber balling, void formation, and micro-cracks [21] in prepared specimens.







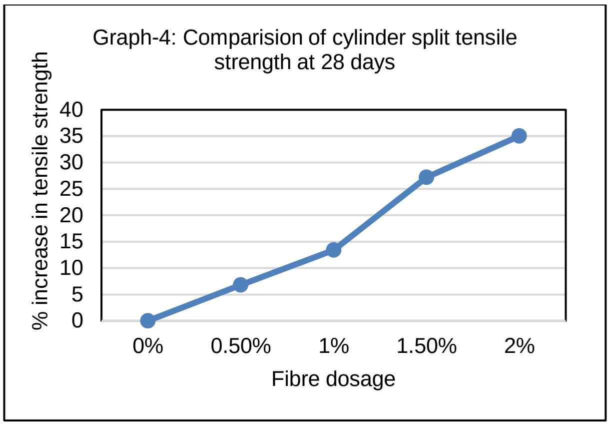


Table 8

Cylinder Split tensile strength in MPa

No. of days	**Glass fiber dosage**				
	0%	0.5%	1%	1.5%	2%
3 days	3.03	3.58	4.12	4.42	4.78
7 days	4.06	4.43	4.68	5.35	5.67
14 days	5.25	5.72	5.96	6.42	6.88
28 days	5.88	6.28	6.67	7.48	7.94
56 days	6.58	6.83	7.06	7.93	8.47

3.2. Split tensile strength

For all mixes, a split tensile test is carried out on a cylinder of size 100 mm diameters x150mm height to study the effect of glass fiber on the tensile strength of concrete. The variation in split tensile strength is shown in Table - 8. We can see that the split tensile strength for fiber dosage of 0%, 0.5%, 1%, 1.5%, 2% at 28 days is 5.525, 5.72, 5.96, 6.42, 6.88 MPa respectively. As the fiber content increases, we can see that the tensile strength also increased considerably [14]. The increase in tensile strength with respect to control mix (0% fiber content mix) for .5%, 1%, 1.5%, 2% are 6.7, 13.43, 27.21, and 35.03 respectively. We can say that increase in fiber dosage resulted in increased tensile strength of the mixture. Graph 3,4 shows the results of split tensile strength of concrete.

3.3. Flexural strength

The flexural test is carried on a beam of size 500x100x100mm to study flexural strength with the change in fiber dosage [26]. The main aim is to convert conventional concrete which is brittle into ductile material by the addition of fiber. The study is done confirming to be standard (IS 516-1959). The test has been done on specimens by using a three-point loading machine. The formula used in calculation of modulus of rupture (fb) or flexural strength is defined as,

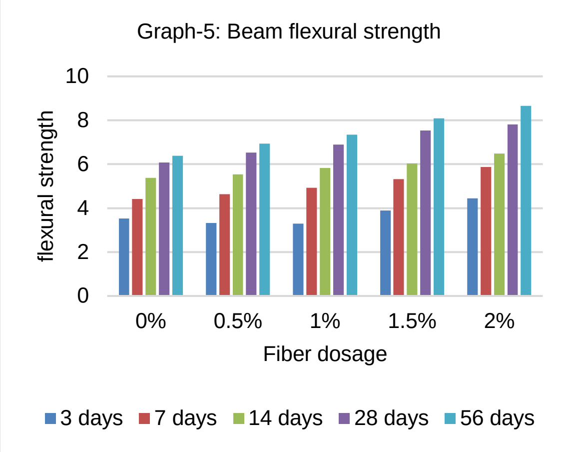
$fb=pl/bd^2$ (when a> 13.0cm for specimens) and

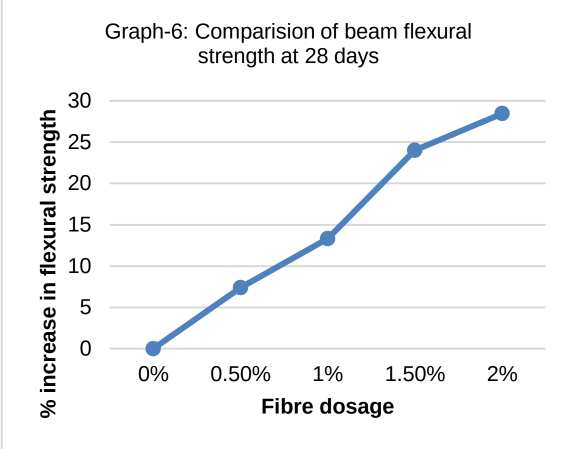
$fb=3pa/bd^2$ (when a<13.3cm but > 11.0cm for specimens)

Table 9

Beam flexural strength in MPa

No. of days	**Glass Fiber dosage**				
	0%	0.5%	1%	1.5%	2%
3 days	3.53	3.33	3.30	3.89	4.44
7 days	4.42	4.64	4.93	5.32	5.87
14 days	5.38	5.54	5.83	6.03	6.49
28 days	6.08	6.53	6.89	7.54	7.81
56 days	6.38	6.94	7.34	8.09	8.66





Where,

'a' represents distance between the line of fracture and the nearer support, measured on the centerline of the tensile side of the specimen.

'b' represents the width of the specimen in cm

'd' represents failure point depth in cm

'l' represents the supported length in cm

'p' represents the maximum load in kg

From the results summarized in the Table 9 we can say that the strength has been increased considerably. From the Table - 9 the 28-day flexural strength for 0%, 0.5%, 1%, 1.5%, 2% are 6.08, 6.53, 6.89, 7.54, 7.81MPa respectively. From the comparison of flexural strength at 28 days graph, we can say that the increase of flexural strength of mixes with higher fiber content showed a higher increase in flexural strength. The increase from Graph – 6 for 0.5%, 1%, 1.5%, 2% fiber dosages with respect to 0% fiber mix are 7.4%, 13.47%, 24.01%, 28.45%. The fiber dosage is restricted to 2% because if it is increased then it results in irregular distribution and intermingling [27]. It is even observed during the study that the proper alignment of the fibers along the direction of flexural strength has resulted in improved strength [13]. Graph 5, 6 shows the different results from flexure strength test of the specimens.

3.4. Impact strength

As per ACI committee 544 guidelines, the falling weight impact test is performed. A steel ball of mass 4.2kg is dropped onto the specimens i.e., a disc of 150mm diameter and 65cm height. After 'n' number of hits we obverse that cracks start to develop. When the crack is formed for the first time it is said initial crack (IC) or first crack. As the number of hits increases, we find a greater number of cracks [28]. The number of hits required for the specimen to finally break and fail is also recorded. The impact of energy has been calculated using the following formula:

$$\text{Impact energy} = n \times m \times g \times h$$

Where,

'n' represents the number of hits required for the crack to appear.

'm' represents the mass of the steel ball used = 4.2kg

'g' represents acceleration due to gravity = 9.81m/sec^2

'h' represents the height of fall of the steel ball used = 50cm

In the study, 20 specimens are prepared for each mix with varying fiber content. Then the falling weight impact test is done on the specimens

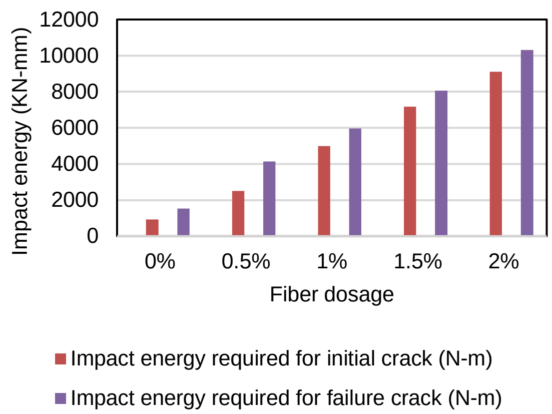
Table 10

Impact strength on disc (N-m) at 28 days

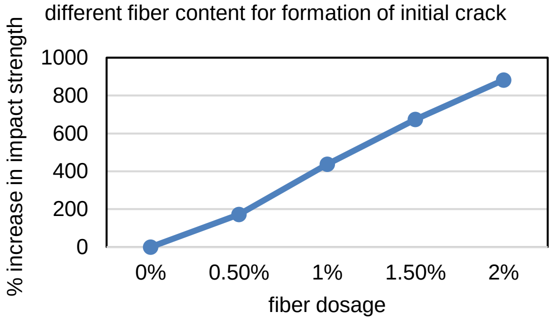
Fiber dosage	No. of blows for initial crack (IC)	Impact energy (N-m)	No. of blows for failure crack (FC)	Impact energy (N-m)
0%	45	927.045	74	1524.474
0.5%	122	2513.322	201	4140.801
1%	242	4985.422	290	5974.29
1.5%	348	7169.148	391	8054.99
2%	442	9105.642	501	10321.101

and data is recorded in Table - 10. We can see that from the table that with an increase in the fiber content there is an increase in the impact energy comparatively [29]. From the Table- 10 we can say that number of hits required for initial crack (IC) for fiber content 0%, .5%, 1%, 1.5%, 2% is 45, 122, 242, 348, 442 respectively and number of hits required for failure crack is 74, 201, 290, 391, 501 respectively. From the graph- we can say that % increase in impact energy at initial crack for fiber dosages .5%, 1%, 1.5%, 2% is 171.1%, 437.77%, 673.33%, 882.2% respectively with respect to 0% fiber content mix (control mix). From the Graph 7, 8, 9, we can tell that % increase in impact energy at failure crack for fiber dosage .5%, 1%, 1.5%, 2% is 171.62%, 291.89%, 428.37%, 577.027% respectively with respect to 0% fiber content mix (control mix).

Graph-7: Impact strength on disc at 28 days

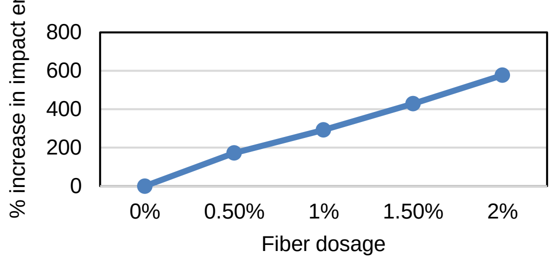


Graph-8: Comparision of impact strength for different fiber content for formation of initial crack



In recent years, many methods of statistical analysis have been evolved [16]. Out of which normal distribution, binomial distribution as well as Weibull distributions are famous. Weibull distribution is used in the present study. Weibull analysis is a methodology used for the measurement of a product's life using a relatively small sample size of laboratory data [30]. In the study, we have used a two-parameter Weibull analysis for analyzing the changes in impact test data. For the data obtained in the Table 11 Weibull analysis has been done and the results

Graph-9: Comparision of impact strength of different fiber content for the formation of failure crack



are represented both in the form of a graph and in the table format.

The Weibull distribution can be defined by shape parameter (γ) and scale parameter (α), the cumulative distribution function is

$F_N(n) = 1- \exp\{(-(n-n_0)/(\alpha-n_0))^{\gamma}\}$

Where,

'n' represents the particular value of the random variable F;

'n_0'represents the location parameter, and $n \geq n_0$, $\gamma>0$, $\alpha \geq n_0$.

Then the probability of survivorship function can be written as

$L_N(n) = 1- F_N(n)$

When the minimum life of concrete, n_0 is assumed to be zero in the case of application of impact loading, the equation is transformed into

$L_N(n) = \exp(-(n/\alpha)^{\gamma})$

On applying logarithms on left and right sides we get,

$$\ln[\ln(1/L_N)] = \gamma\ln(n) - \gamma\ln(\alpha)$$

The above equation can be transformed into

$$Y = \gamma X - \beta$$

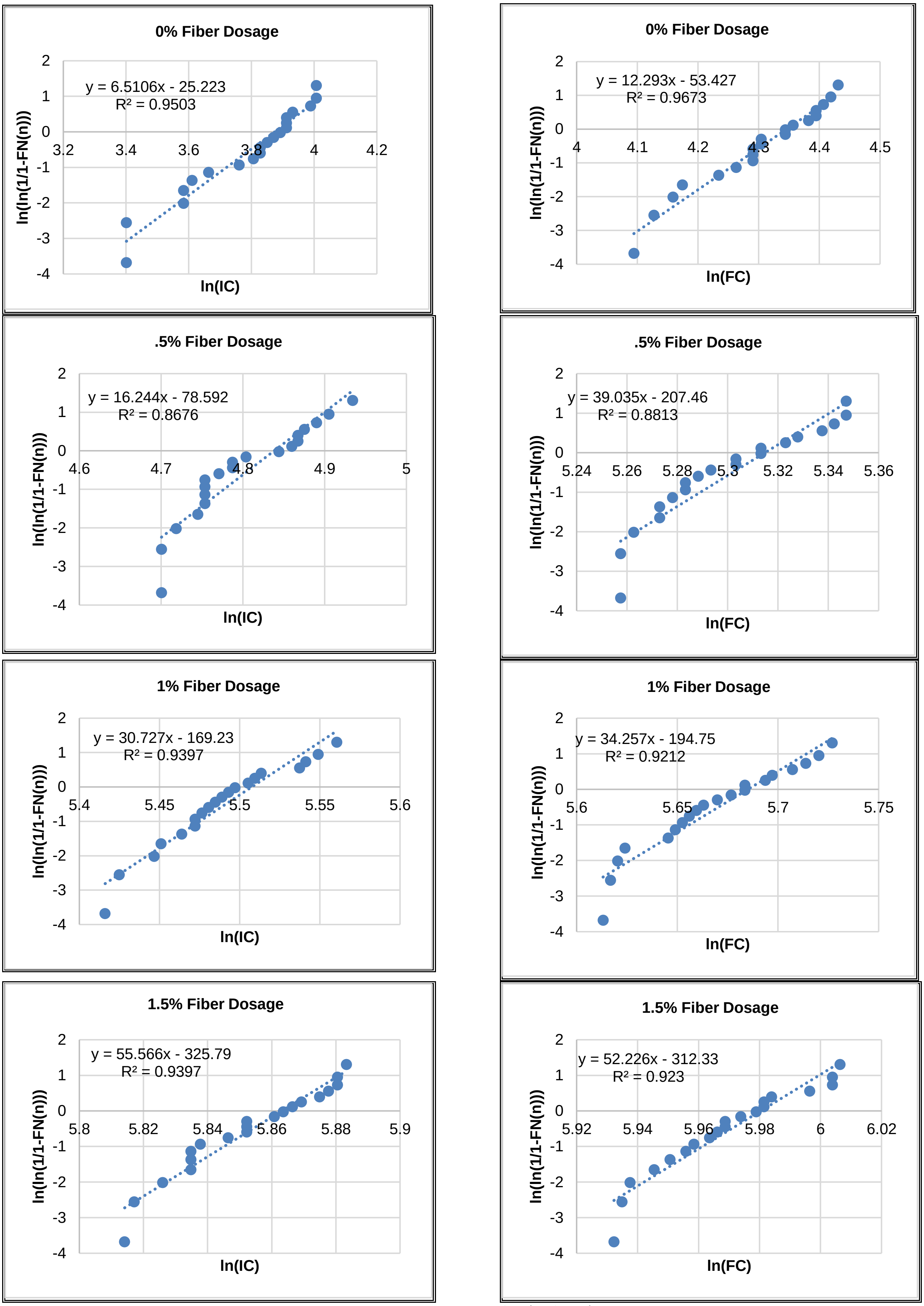
By considering, $Y = \ln[\ln(1/L_N)]$, $X = \ln(n)$, $\beta = \gamma\ln(\alpha)$

The probability estimator used in the study is FN= (i-.5)/k

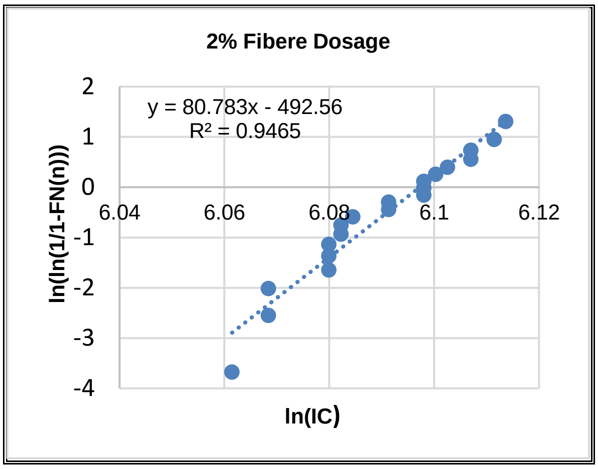
Where, i is rank when the failure of the specimens occurs,

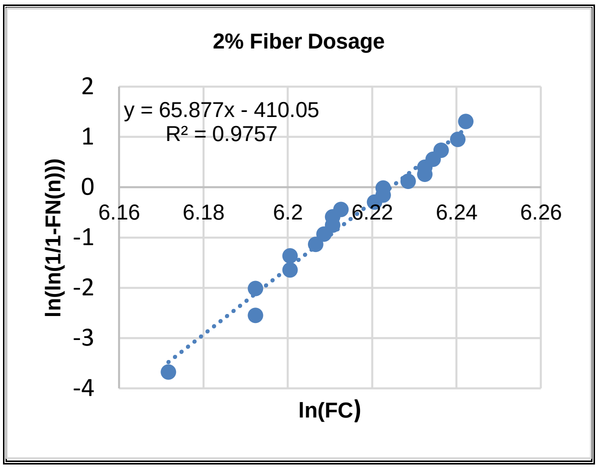
k is the total number of specimens cast for each mix.

We have considered this probability estimator because of its simplicity and the value increase from a small regression coefficient to the regression coefficient of 0.9. From the graphs, we can say a linear trend is followed in the linear regression relationship, which says that the two-parameter Weibull theory is the most appropriate method for statistically analyzing variations in impact test data. From the linear Graph.10, we can find the slope which is the shape parameter (γ) and the intercept of the line gives us the value of β. By using β and γ values we can find the scale parameter (α). The parameters and determination coefficient (R^2) for all mix are tabulated in Table 12.



Graph. 10 continues on next page





Graph. 10 - Linear graphs showing the slopes for different mixes.

Table-11

Results of impact test

S. No.	Fiber Dosage									
	0%		0.5%		1%		1.5%		2%	
	IC	FC	IC	FC	IC	FC	IC	FC	IC	FC
1	30	77	118	196	238	277	335	389	437	479
2	45	74	139	206	242	288	357	379	432	489
3	55	60	129	201	248	287	348	391	442	493
4	55	77	131	198	232	298	342	393	447	504
5	46	81	127	195	227	294	359	382	429	510
6	43	62	130	203	241	274	353	378	438	509
7	54	74	116	197	236	286	346	390	445	511
8	30	78	110	195	238	294	354	395	449	496
9	50	64	116	210	243	305	358	402	452	497
10	36	73	115	205	225	301	342	406	439	507
11	51	81	133	192	255	297	348	396	449	509
12	50	65	135	209	257	283	339	387	438	513
13	39	80	116	203	244	275	348	384	432	498
14	50	82	120	193	233	290	343	405	446	493
15	36	69	122	201	239	276	356	397	437	504
16	46	73	110	192	246	303	352	391	437	514
17	37	83	116	197	247	307	358	386	445	498
18	48	71	130	208	254	285	342	405	451	489
19	47	84	112	199	260	292	336	377	442	503
20	49	73	120	210	240	284	351	396	445	499
Mean	45	74	122	201	242	290	348	391	442	501
S. D	8	7	9	6	10	10	8	9	7	9

Table 12

Linear regression coefficients and scale parameter of IC & FC in Weibull distribution

Fiber dosage **Initial crack (IC)**

	γ	B	A	R^2
0%	6.511	25.223	48.13	.9503
.5%	16.244	78.592	126.244	.8676
1%	30.727	169.23	246.542	.9397
1.5%	55.56	325.79	352.042	.9397
2%	80.783	492.56	444.665	0.9465

Fiber dosage **Finial crack**

	γ	B	A	R^2
0%	12.293	53.427	77.179	.9673
.5%	39.035	207.46	203.307	.8813
1%	34.257	194.75	294.408	.9212
1.5%	52.226	312.33	395.581	.923
2%	65.877	410.07	505.113	.9757

4. Conclusions

1. In the current study, both silica fume and fly ash are used to increase the strength characteristics of normal concrete to convert it into high strength concrete. From the results obtained we can conclude that the strength properties like split tensile, flexural, and impact strength are improved considerably.

2. The % increase in compressive strength of the 1.5% fiber dosage mix is about 8% when compared to the control mix. Whereas the % increase in compressive strength for fiber dosage of .5%, 1%, and 2% is not high concerning the control mix. So, the mix with 1.5% fiber addition is considered as optimal fiber addition to the normal mix. The same results are observed in other research papers for m30 mix.

3. In the case of split tensile strength, we can say that the tensile strength has increased with increased fiber content with proper orientation. And also, fiber content should be restricted to 2% because the ball formation of fibers is observed which prevents acquiring the required strength. The split tensile strength increase is good for 1.5% fiber addition which is appropriately 28%.

4. In the case of flexural strength also we find that strength increase with fiber increase up to 2%. The increase in flexural strength with 1.5% fiber addition is 24% and for 2% fiber addition is about 29%. But the increase in fiber above 2% does not follow the same trend.

5. In the case of impact strength % increase in impact energy at initial crack for fiber dosages .5%, 1%, 1.5%, 2% is 171.1%, 437.77%, 673.33%, 882.2% respectively. Clearly the absorbed impact strength increases for increase in fiber content. In case of % increase in impact energy at failure crack for fiber dosage .5%, 1%, 1.5%, 2% is 171.62%, 291.89%, 428.37%, 577.027% respectively with respect to 0% fiber content mix (control mix).

6. For analyzing the variations in several impacts for initial and failure crack with the help of two-parameter Weibull theory, exhibits the results with good linear correlation.

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