REDUCEREA PROPRIETĂȚILOR MECANICE ALE BETONULUI ARMAT DISPERS CU FIBRE LA SOLICITĂRI DE IMPACT

LOSS OF MECHANICAL PROPERTIES OF FIBER-REINFORCED CONCRETE EXPOSED TO IMPACT LOAD

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The aim of the study is to investigate the loss of mechanical properties such as compressive and splitting tensile strength of fiber-reinforced concrete (FRC) when exposed to impact load. Two different steel fibers i.e. hooked end and crimped end having the length of 50 mm and an aspect ratio of 50 were used as reinforcing materials in 0.5%, 1.0% and 1.5% volumes with a water-binder ratio of 0.42. The American concrete institute (ACI) committee 544 drop weight test was performed on 28 days cured cylinders, in order to determine the impact failure energy. In order to identify the loss of compressive and splitting tensile strength due to the effect of impact, another set of samples were prepared from the same concrete mixtures and exposed to impact loads of 25%, 40%, and 55% of their impact failure energy. Based on the results obtained from the experimental work, multivariate linear regression (MLR) models were developed using SPSS software to predict the percentage loss of compressive and splitting tensile strength due to the effect of impact load and the validity of the proposed model were verified with the test data of an earlier research. The results showed that the loss of compressive and splitting tensile strength in FRC significantly decreased compared with concrete without fiber, when exposed to impact loads. The results of the proposed model provided good agreement with the experimental results.

Keywords: *Compressive strength, Tensile strength, Fiber, Impact, loss of strength*

1. Introduction

The degree of brittleness of normal and high strength concrete increases as its strength increases and this is considered as a drawback of its mechanical characteristics and also severely affects the performance of concrete, especially under the impact and dynamic loads. In order to deal with this problem, changing the mode of failure from brittle to ductile can be achieved by incorporating various types of steel fibers to cement mixtures [1, 2]. Adding steel fibers to concrete increases many properties such as flexural strength, tensile strength, ductility, failure toughness, wear resistivity, resistance against impact, and fatigue loads [1–5]. The most considerable effect of fiber-reinforced concrete (FRC) is that it arrests the development of crack formation within the concrete; furthermore, the initiation and expansion of micro-scale cracks in FRC resulting in fiber themselves bears some of the internal stresses. When the load increases, the fiber tends to transfer the excess stresses to the other region of matrix. This behavior displayed by the FRC under stress makes the FRC superior to nonfibrous concrete [6–8].

The FRC is widely used nowadays in the construction industry (such as bridges, piles, industrial floors, military buildings, and airport runway pavements) where the impact loads are enormous, and hence these concrete play a vital role in construction industry. The impact resistance of nonfibrous concrete is quite insufficient, as a result of which cracks occur and propagate randomly in the nonfibrous concrete structure. Thus, the mechanical properties and durability of concrete gets reduced, which makes it unable to deliver the performance expected from the material. In order to assess the efficiency of steel fiber concrete under impact loading, it is necessary to determine the extent of mechanical losses caused in the concrete due to impact loads. For this purpose, the mechanical properties of FRC under impact loads corresponding to various proportions of impact failure energies were examined in this study. Further a Multivariate Linear Regression analytical (MLR) model was developed using SPSS software to find the loss of mechanical properties of FRC exposed to different level of impact loads.

2. Experimental Details

2.1 Material properties

Ordinary Portland cement 53 grade corresponding to ASTM Type I cement with a specific gravity of 3.15 was used in concrete mixtures. Crushed granite gravel with a size of 12 and 20 mm and the specific gravity of 2.71 and 2.77 were used as the coarse aggregate. The natural

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Table 1

Concrete mix proportions for 1 m^3.

Mix id	W/B	Water (kg/m^3)	Cement (kg/m^3)	Fine Agg. (kg/m^3)	Coarse Aggregate (kg/m^3)		Volume fraction V_f	Weight of fiber (kg/m^3)	Sp (%)
					20 mm	12 mm			
PC	0.42	140	333	901	465	697	–	–	0.3
CF2	0.42	140	333	903	460	689	0.5	39	0.5
CF3	0.42	140	333	892	454	681	1.0	78	0.8
CF4	0.42	140	333	885	450	676	1.5	117	1.0
HF5	0.42	140	333	903	460	689	0.5	39	0.5
HF6	0.42	140	333	892	454	681	1.0	78	0.8
HF7	0.42	140	333	885	450	676	1.5	117	1.0

siliceous river sand having a specific gravity of 2.64 was used as a fine aggregate. A commercial high-performance superplasticizer (Sp) (polycarboxylic ether) was used as a high-range water-reducing agent to produce a workable fiber-reinforced concrete. The slump value was maintained for all the mixtures as 75 mm ± 5 mm with the help of high range water reducing admixtures at the dosage of 0.3% to 1.0% from the weight of cement. Two different fibers, namely crimped fiber (CF) and hooked end fiber (HF) with an aspect ratio 50, and having a length of 50 mm and equivalent diameter of 1 mm were used. The density of both the fibers was 7.8 g/cm^3.Tensile strength of crimped and hooked end fiber was 1000 MPa and 1050 MPa, respectively.

2.2 Mix proportions

In this study, water cement ratio of 0.42 was adopted for M30 grade concrete. Different steel fibers namely crimped and hooked end fibers of 0%, 0.5%, 1.0% and 1.5% volume fraction were used. In total, seven mix proportions were prepared and their materials and code specifications are listed in Table 1.

2.3 Mixing procedure and specimens

The mixing procedure was adopted by trial and error method as follows: in the beginning, the fine aggregate and cement were mixed for 1 minute, and half of the mixing water and Sp were added to the mix and then it was mixed again for 2 minutes. The remaining water was added to the mix along with coarse aggregate and mixed for 5 minutes. Finally, fibers were added in various proportions such as 0.5%, 1.0% and 1.5% to the mixture and the mixing was done for 5 minutes as per the literature [1, 2]. Cylindrical (150 × 64 mm) discs were prepared for the compressive, splitting tensile and impact strength tests. These tests were conducted in accordance with the ASTM C39 and ASTM C496 standards [9, 10].

A total of 189 cylindrical discs were used in this study. Out of these, 42 cylindrical discs were used for determining the compression and splitting tensile strength prior to impact loading and another 21 cylindrical discs were used for determining the impact failure energy of plain and FRC. Remaining 126 cylindrical discs were used to determine the compression and splitting tensile strength of concrete exposed to impact load of 25%, 40% and 55% of impact failure energy.

2.4 Impact test

The impact resistance of the specimens was determined in accordance with the procedure proposed by the ACI committee 544.2R-89 [7]. The impact test was carried out using drop weight hammer for cylindrical disc specimens. In drop weight hammer test the cylindrical disc were placed on the base plate of impact testing machine. The impact load was applied with a 44.5 N hammer dropped repeatedly from a height of 457 mm onto the discs. In this test the number of blows required to cause complete failure of the specimen was recorded as the impact failure strength and this method was used by several researchers [1, 2, 11–15].

The impact energy delivered by the hammer per blow is calculated as follows:

$$\text{Impact energy U} = \left(\frac{\text{m.V}^2}{2}\right).\text{n} = mgh.n \quad (1)$$

$$h = \left(\frac{gt^2}{2}\right) \quad (2)$$

$$\text{V} = \text{g.t} \quad (3)$$

$$\text{m} = \frac{\text{W}}{\text{g}} \quad (4)$$

Where *V* is the velocity of the hammer at impact, *g* is acceleration due to gravity, and *t* is the time required for the hammer to fall from a height of 457 mm. *H* is the height of the fall, *m* is mass of the hammer and *W* is the weight of the hammer.

Substituting the relevant values in Equation (2) yields:

$$457 = \frac{9810t^2}{2},$$

$$\text{t} = 0.3052 \text{ s and V} = 9810 \text{ x } 0.3052 = 2994.01 \text{ mm/s}.$$

The impact failure energy per blow, U, of the hammer can be obtained by substituting the values in Eq '(1)'.

$$\text{U} = \frac{44.3\text{x}2994.01^2}{2\text{x}9810} = 20.345 \text{ kNmm}.$$

3. Results and Discussion

The compressive strength, splitting tensile strength and impact failure energy for the plain concrete (PC) and FRC are shown in Table 2. The losses in the compression and splitting tensile strength of PC and FRC versus the level of impact load employed are given in Figure [1 to 4]. Table 3 shows the impact failure energy of PC cylindrical specimen found to be 1388.55 kN mm, whereas the values are obtained in the range of 3072.10–6169.62 kN mm and 3321.32–6408.68 kN mm for the crimped and hooked end steel FRC respectively. Similarly the impact failure energy of PC for prism was found to be 450.98 kN mm, whereas the values were obtained in the range of 518.80–722.25kNmm and 573.05 – 779.89 kN mm for the crimped and hooked end steel FRC respectively.

The impact energy of crimped and hooked end steel FRC was increased up to 4.4 and 4.6 times, respectively, compared with PC depending upon the existing volume fraction of the fiber. The impact resistance of FRC increases due to the increase in volume fraction of fiber [1, 2, 10 –18].

Table 2

Average experimental test results

Mix Id	Mechanical properties prior to impact loading (N/mm^2)		Impact failure energy (kN mm)
	f_{cs}	f_{ts}	Cylindrical disc
PC	64.40	3.75	1388.55
CF2	83.16	4.21	3072.10
CF3	89.22	4.68	4714.95
CF4	106.96	5.11	6169.62
HF5	80.07	4.08	3321.32
HF6	85.47	4.48	4887.89
HF7	103.78	4.98	6408.68

f_{cs}- Compressive strength of cylinder, f_{ts}- Splitting tensile strength of cylinder

The mechanical properties of plain and FRC exposed to various levels of impact load are shown in Table 3. It was observed that for the cylindrical disc exposed to the level of 25% of their impact failure energy, the loss in compressive strength of PC was 45%, whereas it was between 25% and 18% for crimped steel FRC (CF2–CF4) and between 22% and 16% for hooked end steel FRC (HF5–HF7). For the cylindrical disc exposed to the level of 40% of their impact failure energy, losses in compressive strength of PC were 63%, whereas it was between 44% and 33% for crimped steel FRC (CF2–CF4) and between 41% and 31% for hooked end steel FRC (HF5–HF7). For the cylindrical disc exposed to the level of 55% of their impact failure energy, losses in compressive strength of PC were 73%, whereas it was between 67% and 61% for crimped steel FRC (CF2–CF4) and between 63% and 60% for hooked end steel FRC (HF5–HF7). The results show that loss of compressive strength in FRC, when exposed to three different levels of impact (25%, 40% and 55%) was less when compared to PC. In the case of FRC, the loss of compressive strength decreased as the volume fraction of fiber increased [6]. As it can be seen from Figures [1 and 2], the least loss of compressive strength after the three levels of impact effect was obtained from the specimens that contain 1.5% volume fraction of fiber.

The splitting tensile strength of PC and FRC specimens exposed to the level of 25% of their impact failure energy, the amount of loss occurred in PC was 45% whereas it was between 37% and 22% for crimped steel FRC (CF2–CF4) and between 35% and 20% for hooked end steel FRC (HF5–HF7). For the cylindrical concrete specimen exposed to the level of 40% of their impact failure energy, the amount of loss occurred in splitting tensile strength of PC was 49%, whereas it was between 50% and 38% for crimped steel FRC (CF2–CF4) and between 48% and 36% for hooked end steel FRC (HF5–HF7). For the cylindrical

Table 3

Average mechanical properties at various levels of the impact loads

Mix id	Mechanical properties and the level of the impact loads employed (N/mm^2)					
	25% of impact failure energy		40% of impact failure energy		55% of impact failure energy	
	f_{cs}	f_{ts}	f_{cs}	f_{ts}	f_{cs}	f_{ts}
PC	35.69	2.06	23.69	1.92	17.56	1.46
CF2	64.78	2.72	49.13	2.19	31.00	1.53
CF3	70.20	3.28	57.82	2.75	34.02	2.29
CF4	90.09	4.08	73.40	3.25	42.56	1.82
HF5	59.78	2.59	44.67	2.02	26.73	1.39
HF6	66.58	3.02	54.20	2.59	32.27	2.09
HF7	85.60	3.88	69.49	3.09	40.00	1.73

concrete specimen exposed to the level of 55% of their impact failure energy, the amount of losses in splitting tensile strength of PC were 61%, whereas it was between 66% and 53% for crimped steel FRC (CF2-CF4) and between 64% and 51% for hooked end steel FRC (HF5-HF7). From the results of three levels of impact effects, the fewer amounts of losses in splitting tensile strength was observed in FRC than the PC. For FRC the losses in splitting tensile strength were decreased as the volume fraction of fiber increased [6]. Figure [3 and 4], shows the least amount of loss in splitting tensile strength from the 1.0% and 1.5% volume fraction of FRC.

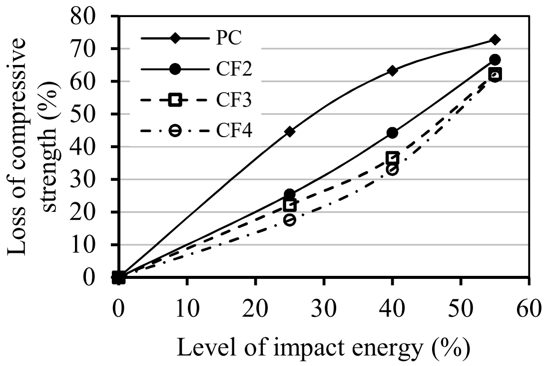

Fig. 1 - Loss of compressive strength versus level of impact energy for the crimped steel FRC.

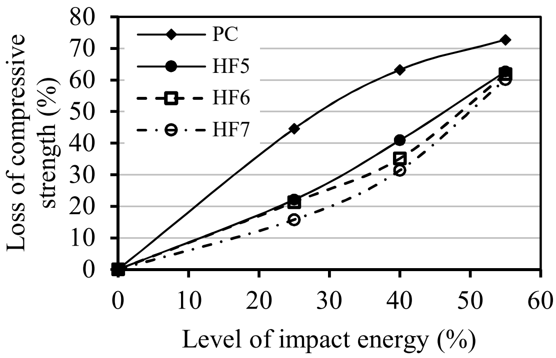

Fig. 2 - Loss of compressive strength versus level of impact energy for the hooked end steel FRC.

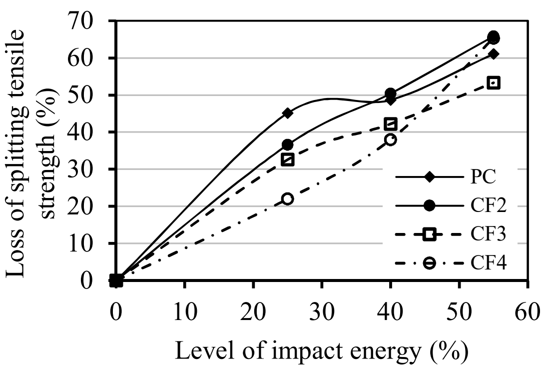

Fig. 3 - Loss of splitting tensile strength versus level of impact energy for the crimped steel FRC.

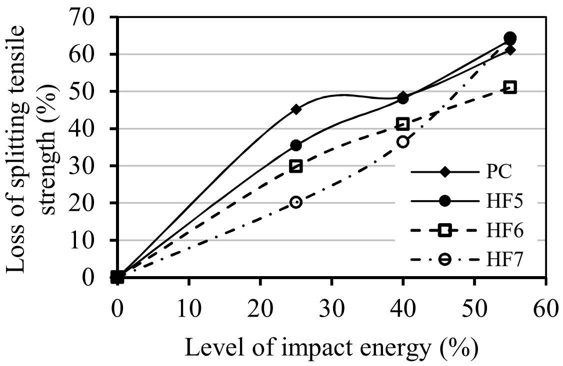

Fig. 4 - Loss of splitting tensile strength versus level of impact energy for the hooked end steel FRC.

It can be concluded from the above investigation that when the concrete exposed to various level of impact loads of their impact failure energy, the PC had 1.2–2.8 times the loss in compressive strength and 1.2–2.2 times the loss in splitting tensile strength compared to FRC. The best performance was obtained from the concrete incorporating hooked end steel fiber.

4. Loss of mechanical properties-Analysis and Modeling

Percentage loss of mechanical properties (dependent variable) of FRC when exposed to impact loads of 25%, 40% and 55% of their impact failure energy were considered as a function of the following four input parameter (independent variable).

(i) Level of the impact loads employed (x_1)(ii) Volume fraction of fiber (x_2) (iii) Aspect ratio (x_3) and (iv) Tensile strength of fiber (x_4).

The loss of mechanical properties of FRC exposed to impact load greatly depends upon the four parameters and hence these parameters were used in regression analysis to establish a relationship between the dependent and independent variables.

In MLR analysis, it is assumed that the variable y is related to variables x_1, x_2, x_3,. x_n, for which an individual value of y is defined as:

$$y = a_0 + \sum a_i x_i \quad (i=1\ ton) \qquad (5)$$

The mathematical model for predicting percentage loss of mechanical properties exposed to impact load is expressed by a linear equation (6 & 7) by rewriting the Equation (5) in the expanded form as:

$$y_1 = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 \qquad (6)$$

$$y_2 = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 \qquad (7),$$

where y_1 and y_2 is the estimated percentage loss of compression and splitting tensile strength respectively exposed to impact loads of 25, 40, and 55% of their impact failure energy or dependent variable, n is the number of parameters; a_o, b_o, c_o and a_i, b_i, c_i (a_1 to a_4, b_1 to b_4 and c_1 to c_4), are the regression coefficients, (i =1 to 4), and x_1, x_2......x_4 are the independent variables.

Table 4

Experimental and predicted value

Mix id	Level of impact load employed	% Loss of compressive strength			% Loss of splitting tensile strength		
		AV	PV	PD	AV	PV	PD
PC	25	45	40	10	45	37	17
CF2	25	25	25	3	37	35	5
CF3	25	22	21	5	33	31	7
CF4	25	18	17	0	22	26	-19
HF5	25	22	23	-3	35	33	5
HF6	25	21	19	11	30	29	4
HF7	25	16	15	2	20	24	-21
PC	40	63	60	4	49	52	-5
CF2	40	44	45	-1	50	50	1
CF3	40	37	41	-11	42	45	-7
CF4	40	33	37	-13	38	41	-7
HF5	40	41	43	-4	48	48	0
HF6	40	35	39	-11	41	43	-5
HF7	40	31	35	-13	36	39	-7
PC	55	73	80	-10	61	66	-8
CF2	55	67	65	4	66	64	3
CF3	55	62	61	2	53	60	-12
CF4	55	61	57	6	65	55	15
HF5	55	63	63	1	64	62	3
HF6	55	62	59	5	51	58	-13
HF7	55	60	55	8	64	53	17

AV: Actual Value, PV: Predicted value, PV: percentage difference.

Table 5

Experimental and predicted value of earlier researcher [6]

Mix id	Level of impact load employed (x_1)	Volume fraction of fiber (x_2)	Aspect Ratio (x_3)	Tensile strength MPa (x_4)	% loss of compressive strength			% loss of splitting tensile strength		
					AV	PV	PD	AV	PV	PD
CC1	25	0	-	1250	45	40	10	43	37	13
FRC1	25	0.5	45	1250	23	22	5	33	31	5
FRC2	25	1.0	45	1250	22	18	17	27	27	1
FRC3	25	1.5	45	1250	15	15	2	19	22	-16
CC1	40	0	-	1250	66	60	9	48	52	-8
FRC1	40	0.5	45	1250	44	42	5	46	46	1
FRC2	40	1.0	45	1250	38	38	-1	40	41	-3
FRC3	40	1.5	45	1250	34	35	-2	35	36	-4
CC1	55	0	-	1250	78	80	-3	62	66	-7
FRC1	55	0.5	45	1250	67	62	8	63	60	5
FRC2	55	1.0	45	1250	63	58	8	50	55	-11
FRC3	55	1.5	45	1250	61	55	10	63	51	19

The statistical models (equation for loss of compression and splitting tensile strength) was developed using SPSS software package as given in equation (9) and (10). The correlation coefficients for y_1& y_2 was found to be 0.985 and 0.935 respectively

$$y_1 = 7.19 + (1.329 * x_1) + (-7.167 * x_2) + (0.557 * x_3) + (-0.04 * x_4) \quad (9)$$

$$y_2 = 13.19 + (0.962 * x_1) + (-9.167 * x_2) + (0.808 * x_3) + (-0.0378 * x_4) \quad (10)$$

It can be seen in Table 4 that the predicted value of percentage loss of compression and splitting tensile strength exposed to impact loads of 25, 40, and 55% of their impact failure energy is obtained from the equation (9) and (10). The proposed models are in good agreement with the experimental and predicted value. Moreover the maximum difference between the experimental and predicted value was 13 % for loss of compressive strength, 21% for loss of splitting tensile strength and hence a higher accuracy is being achieved as shown in Table 5. The validity of the model was investigated by examining the statistical coefficient with earlier researcher [6]. Table 5 shows the comparisons of percentage loss of compressive and splitting tensile strength and it was found to have good correlation with the experimental data. In the view of convenience and generality, the statistical model is accurate and preferable to evaluate the loss of mechanical properties of FRC exposed to impact load without carrying out the drop weight test.

5. Conclusions

Based on the results obtained from the experiments, the following conclusions are drawn:

1. The impact resistance of FRC displayed is much higher than the plain concrete.
2. Concrete containing crimped and hooked end steel FRC, increased the impact failure energy by 4.4 and 4.6 times compared to plain concrete.
3. The plain concrete yields more than 1.2–2.8 times loss in compressive strength and 1.2–2.2 times more the loss in splitting tensile strength compared to FRC.
4. Best performance was obtained from the concrete when it was exposed to impact loading at the volume fraction of 1.5%. The impact resistance of concrete was increased and losses in mechanical properties in terms of their compressive and splitting tensile strength were decreased as the volume fraction of fiber increased.
5. A Multivariate Linear Regression analytical model was developed using SPSS software to find the loss of mechanical properties of FRC exposed to different level of impact loads. Prediction of percentage loss of mechanical properties exposed to different level of impact load by MLR models was found to be adequate and this approach can easily be adopted due to its explicit nature of equations containing multivariables which influence the percentage loss of mechanical properties of FRC exposed to impact loads.
6. The applicability of the statistical models was verified with the test data of earlier researchers and it was found to be in good correlations with experimental data. This MLR model will reduce the dependency of the number of experiments.

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