FINITE ELEMENT ANALYSIS OF REINFORCED CONCRETE BEAMS WITH FIBERS ADDED TO THE MIX

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Abstract

Concrete structures may be subjected to very high loads, and these loads affect the behavior and safety of the various structure elements, so a lot of methods and studies were made to develop the design methods for these structure elements, and enhancing its strength. One of these methods, use steel fiber in concrete structure elements mix for strengthening. [9]. Based an experimental studies on normal strength and high strength reinforced concrete beams with steel fiber added to the mix, the program numerical simulation by nonlinear finite element method using computer program ANSYS (Version 14.5) [4] was adopted, a total of forty six finite element beam models are investigated. Eighteen Normal Strength Reinforced Concrete (NSRC) [10] beam models and twenty eight High Strength Reinforced Concrete (HSRC) [15] beam models, all of these beam models having steel fibers over partial, such as lower half or one third of the full length of beam span or full depth all over beam span length, with volume fraction is 0.0%, 1.0%, 1.5% and 2.0% for NSRC beams, while it was 0.0%, 0.25%, 0.5% 0.75%, 1.0%, 1.5% and 2.0% for HSRC beams. An approach, the steel fibers were assumed as smeared reinforcement layers uniformly distributed in three orthogonal directions of SOLID65 elements used in the analysis which is more accurate and fiber will modeled as it was expected to provide resistance to crack propagation.
The results such as crack pattern, failure modes, loads deflection curves, stiffness, ductility index and energy absorption for the beam models were studied by this program.

Based on this study and analysis of these results, it was found that we can make suggestions to enhance shear and flexural strength for reinforced concrete beams, such as adding steel fiber.

Keywords: Finite Element; Normal Strength, High Strength; Steel Fiber; Crack pattern;

Introduction

Steel fiber reinforcement concrete (SFRC) [14] is considered as a method of strengthening structural elements such as beams, and it was used to enhance flexural strength and shear strength of the concrete beams. This current research program was conducted to study enhancing the behavior of reinforced concrete beams by adding steel fiber in the mix.. An experimental study was conducted for nine reinforced concrete beams. Three beams specimens were casted without steel fiber and having different steel ration used as control beams, the other six beams considered the variation of reinforcement steel ratio, variation of steel fiber volume and steel fiber location in the mix. This research includes studying the crack patterns, failure modes, loads deflection relationship, steel strains, the stiffness degradation, ductility ratio, energy absorption, and stiffness degradation.

Program of Study

The analyzed beams as shown in Table (1) and Table (2) were carried out on two types of concrete normal strength reinforced concrete (NSRC) and high strength reinforced concrete (HSRC), the first type (NSRC) consists eighteen simply supported beams subjected to a four-point-bending test with steel fiber ratio varying from (0.00% to 2.00%). All the beams had constant span, depth and width of 2000 mm, 300mm and 150mm respectively. Each of the four series comprised beams of different longitudinal tensile reinforcement and steel fiber ratio. The second type (HSRC) consists twenty eight simply supported beams subjected to a four-point-bending test. All the beams had constant span, depth and width of 1500 mm, 250 and 120 mm, respectively. Each of the four series comprised seven beams of different steel fiber ratio varying from (0.0% to 2.00%) and span to depth ratio, span to depth ratios of these series were (1.50, 1.70, 2.00 and 2.20) respectively. Some of (NSRC) beams were tested by Shereen El-tahlawi (2013) [3] with average concrete characteristic strength f_{cu} equal 32 MPa, while for (HSRC) some of beams were tested by Ahmed Yosri (2014) [2] the average concrete characteristic strength f_{cu} equal 55 MPa. Reinforcement of NSRC beams chosen to be as 1.0 %, 1.34% and 2.23% respectively, while reinforcement of all HSRC beams was constant 1.34 %, that is to insure failure stage must be in shear not in flexure (i.e. all beams have adequate flexure strength).

In rail way reinforced concrete bridges, beams which have heavy reinforcement subjected to two concentrated loads as wheels loads, one of most convents methods of enhancing shearing strength capacity is adding steel fiber to the concrete mix, which can be achieve according to the percentage and location of fibers concluded at the end of this study.

Table (1): Specimen Details for (NSRC)

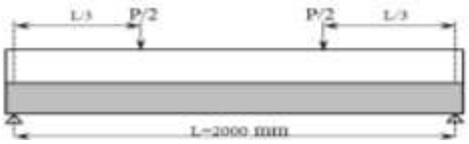
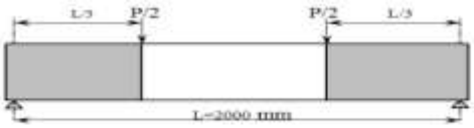
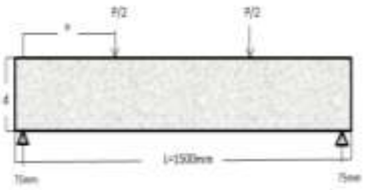
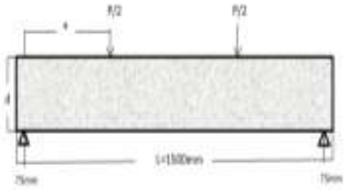
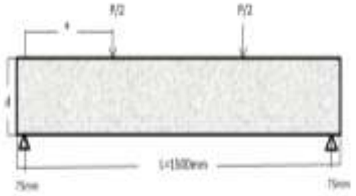
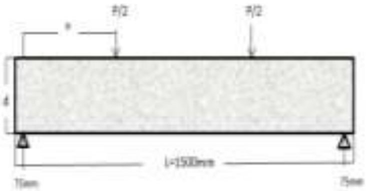
Groups	**Beams**	**Dimensions**	A_S	A_S`	**Stirrups**	V_f
Group A	A-1		4Ø12	2Ø10	5Ø8/m	0.00%
	A-2		3Ø16	2Ø10	5Ø8/m	0.00%
	A-3		5Ø16	3Ø10	6Ø8/m	0.00%
Group B	B-1		5Ø16	3Ø10	6Ø8/m	1.00%
	B-2					1.50%
	B-3					2.00%
Group C	C-1		4Ø12	2Ø10	5Ø8/m	1.00%
	C-2					1.50%
	C-3					2.00%
	C-4		3Ø16	2Ø10	5Ø8/L`	1.00%
	C-5					1.50%
	C-6					2.00%
	C-7		5Ø16	3Ø10	6Ø8/m	1.00%
	C-8					1.50%
	C-9					2.00%
Group D	D-1		5Ø16	3Ø10	6Ø8/m	1.00%
	D-2					1.50%
	D-3					2.00%

Table (2): Specimen Details for (HSRC)

Groups	a/d	Beams	Dimensions	A_S	$A_S`$	Stirrups	V_f
Group A	1.5	A-1		2Ø16	2Ø12	7Ø8/m	0.00%
		A-2		2Ø16	2Ø12	7Ø8/m	0.25%
		A-3		2Ø16	2Ø12	7Ø8/m	0.50%
		A-4		2Ø16	2Ø12	7Ø8/m	0.75%
		A-5		2Ø16	2Ø12	7Ø8/m	1.00%
		A-6		2Ø16	2Ø12	7Ø8/m	1.50%
		A-7		2Ø16	2Ø12	7Ø8/m	2.00%
Group B	1.7	B-1		2Ø16	2Ø12	7Ø8/m	0.00%
		B-2		2Ø16	2Ø12	7Ø8/m	0.25%
		B-3		2Ø16	2Ø12	7Ø8/m	0.50%
		B-4		2Ø16	2Ø12	7Ø8/m	0.75%
		B-5		2Ø16	2Ø12	7Ø8/m	1.00%
		B-6		2Ø16	2Ø12	7Ø8/m	1.50%
		B-7		2Ø16	2Ø12	7Ø8/m	2.00%
Group C	2.0	C-1		2Ø16	2Ø12	7Ø8/m	0.00%
		C-2		2Ø16	2Ø12	7Ø8/m	0.25%
		C-3		2Ø16	2Ø12	7Ø8/m	0.50%
		C-4		2Ø16	2Ø12	7Ø8/m	0.75%
		C-5		2Ø16	2Ø12	7Ø8/m	1.00%
		C-6		2Ø16	2Ø12	7Ø8/m	1.50%
		C-7		2Ø16	2Ø12	7Ø8/m	2.00%
Group D	2.2	D-1		2Ø16	2Ø12	7Ø8/m	0.00%
		D-2		2Ø16	2Ø12	7Ø8/m	0.25%
		D-3		2Ø16	2Ø12	7Ø8/m	0.50%
		D-4		2Ø16	2Ø12	7Ø8/m	0.75%
		D-5		2Ø16	2Ø12	7Ø8/m	1.00%
		D-6		2Ø16	2Ø12	7Ø8/m	1.50%
		D-7		2Ø16	2Ø12	7Ø8/m	2.00%

Numerical Analysis

A three dimensional finite-element program ‘ANSYS’ Ver.14[14] was used for the numerical analysis of the previous beams. In the analysis, appropriate material models were employed to represent the behavior of concrete, steel reinforcement and steel fibers. They are described in detail in the ANSYS manual set in addition to model the bond behavior interface element.

A solid element, SOLID 65, is used to model the concrete in ANSYS. The solid element has eight nodes with three transitional degrees of freedom at each node. In addition, the element is capable of simulating plastic deformation, cracking in three orthogonal directions, and crushing. The steel plates at the supports for the beams are modeled using Solid45 elements. This element has eight nodes with three degrees of freedom at each node – translations in the x, y, and z directions. in order to obtain the internal strains in the reinforcement bars and keep them in their right positions, the discrete technique using the 3D spar Link8 element is followed. This element has two nodes with three degrees of freedom translations in the x, y, and z directions. This element is also capable of plastic deformation. The equivalent fiber reinforcement is considered smeared in the finite element in three orthogonal directions that coincide with the Cartesian directions [6].

In this study the all beams were tested under two-point load, in case of NSRC beams it was at a distance of one over third of span length from support to support, while in case of HSRC beams the distance of load from the support equal to a distance (a) to study the effect of a/d variable.

The following two figures Figure (1) and Figure (2) respectively indicate the details of concrete dimensions of beam and cross section, supporting and loading plates used in the finite element program analysis for both NSRC and HSRC beams respectively.

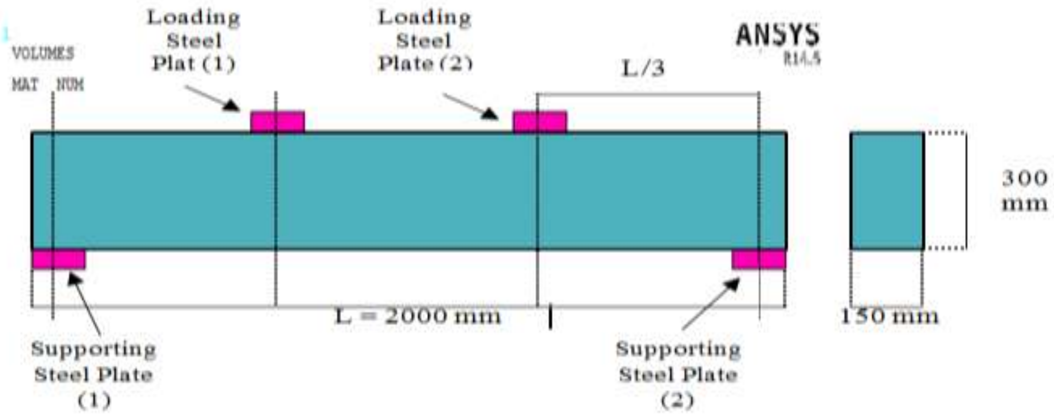


Figure (1): Concrete Dimensions of NSRC Specimens

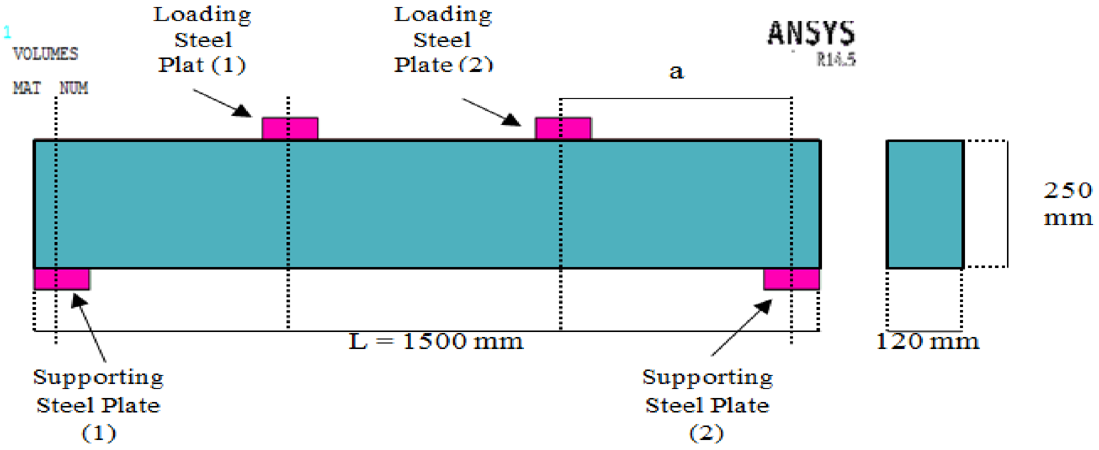


Figure (2): Concrete Dimensions of HSRC Specimens

Theoretical Results

In the following, the results and behavior of beam models with normal strength reinforced concrete (NSRC) is discussed listed in Table (3) in detail as cracking and failure stage mode. This table indicates the values of cracking deflection and load and deflection and load at failure stage respectively for all specimens relative to control beam. Also the ductility index and absorbed energy calculated and listed in the same table (3). Finally the mode of failure for each specimens determined according to the final cracks shapes before failure.

Load Deflection Relationship

Referring to Table (3) and Table (4) verify the analyzed beams; it can be noticed that the measured deflection of all beams with steel fiber in the mix is smaller than that of the control beams (A-1) in NSRC and (A-0) in HSRC Specimens. This means that the using steel fiber in the mix enhances the stiffness and ductility of all beams. The amount of stiffness-regain depends on the location of steel fiber in the beam while in third part neighbor to support or in the lower half of the beam (flexural zone). Figure (3) indicates the load – deflection curve for specimen model (C-1) which one of the NSRC beams, while, Figure (6) indicates the load – deflection curve for another specimen model (A-2) which one of the HSRC beams.

Mode of Failure

Failure load and final deflection of all beams listed in Table (3) and Table (4) for NSRC and HSRC specimens respectively, then the mode of failure listed for each beam according to final shape at failure which is shear mode failure of flexure mode failure.

Ductility Index and Absorbed Energy

Also the ductility index and absorbed energy calculated for each beam specimen relative to control beams and listed in Table (3) and (4) for NSRC and HSRC specimens respectively.

Table (3): Finite Element Results of NSRC Specimens

Group	Beam	Cracking Stage		Failure Stage		Ductility Index (μ_d)	Absorbed Energy (KN.mm)	Mode of Failure
		P_{cr} (KN)	Δ_{cr} (mm)	P_f (KN)	Δ_f (mm)			
Group A	A-1	80.53	3.09	140.4	9.67	2.13	1010	Flexural
	A-2	77.46	2.41	177.7	8.74	2.63	1070	Flexural
	A-3	87.81	1.82	226.1	7.52	2.02	1095	Shear
Group B	B-1	104.0	2.22	245.5	10.42	3.68	1850	Shear
	B-2	104.0	2.18	262.6	9.40	3.31	1652	Shear
	B-3	101.6	2.10	301.7	11.25	4.35	2344	Flexural
Group C	C-1	81.45	2.57	162.0	8.68	2.38	958	Flexural
	C-2	100.6	3.08	188.3	11.50	2.73	1517	Flexural
	C-3	105.6	2.94	200.0	9.00	2.06	1194	shear
	C-4	110.7	2.95	203.9	8.97	2.05	1229	Flexural
	C-5	113.1	2.95	213.9	8.52	1.89	1178	Flexural
	C-6	125.8	3.27	220.6	10.13	2.09	1528	shear
	C-7	113.1	2.39	240.5	7.26	2.04	1052	shear
	C-8	115.8	2.42	251.4	7.34	2.03	1107	shear
	C-9	118.8	2.38	265.6	7.05	1.96	1089	shear
Group D	D-1	113.1	2.35	235.7	7.21	2.07	1078	Shear
	D-2	115.0	2.34	255.2	6.85	1.92	1011	Shear
	D-3	117.6	2.55	247.5	6.78	1.66	959	Shear

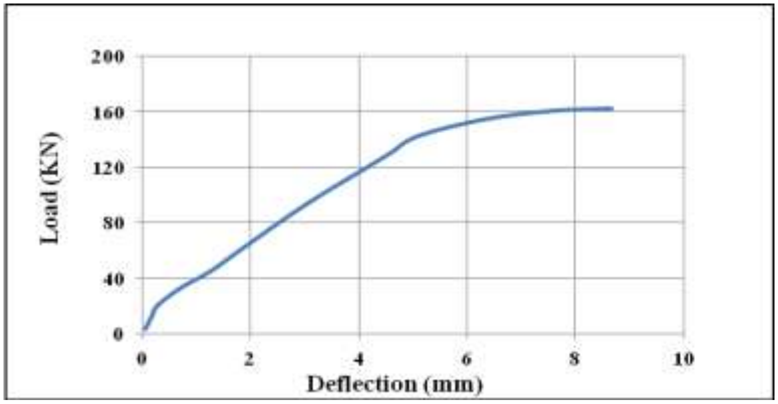


Figure (3): Load-Deflection Curve at Mid Span of Beam Model (C-1) NSRC

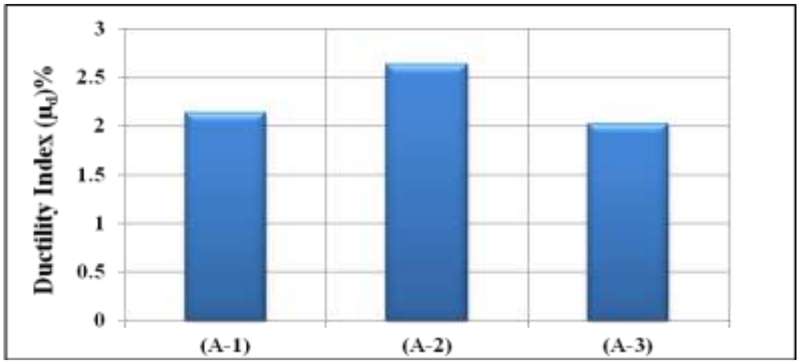


Figure (4): Ductility Index (μ_d) of Group (A) NSRC

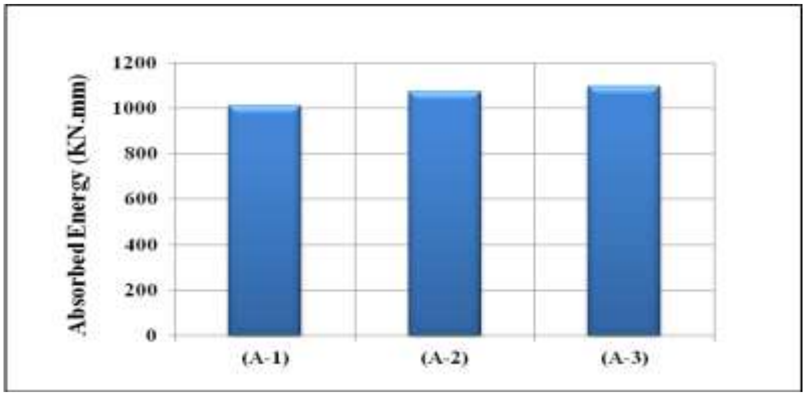


Figure (5): Absorbed Energy of Group (A) NSRC

Table (4): Finite Element Results of HSRC Specimens

Group	**Beam**	**Cracking Stage**		**Failure Stage**		**Ductility Index (μ_d)**	**Absorbed Energy (KN.mm)**	**Mode of Failure**
		P_{cr} (KN)	**Δ_{cr} (mm)**	**P_{ul} (KN)**	**Δ_f (mm)**			
Group A (a/d = 1.5)	A-0	87.52	2.08	160.4	4.76	1.29	466.6	shear
	A-1	97.25	2.30	173.2	7.22	2.14	869.4	shear
	A-2	100.6	2.34	181.7	7.61	2.25	951.8	shear
	A-3	95.00	2.09	205.1	6.96	2.34	922.6	shear
	A-4	92.70	2.01	213.4	6.83	2.40	923.0	Flexural
	A-5	92.40	1.86	228.2	6.42	2.45	890.7	Flexural
	A-6	96.25	1.86	242.9	9.84	4.29	1768	Flexural
Group B (a/d = 1.7)	B-0	77.80	1.98	144.2	4.62	1.33	402.4	Shear
	B-1	81.45	1.99	151.7	4.74	1.38	510.7	Shear
	B-2	81.45	1.95	165.3	5.22	1.67	527.0	Flexural
	B-3	81.85	1.90	179.6	5.84	2.07	656.0	Flexural
	B-4	90.50	2.08	192.1	6.27	2.02	756.0	Flexural
	B-5	92.27	2.02	214.8	7.15	2.54	978.2	Flexural
	B-6	102.0	2.04	232.9	8.23	3.03	1322	Flexural
Group C (a/d = 2.0)	C-0	63.35	1.76	120.9	4.25	1.40	316.2	Flexural
	C-1	75.46	2.04	140.3	6.35	2.09	618.0	Flexural
	C-2	72.40	1.88	151.5	5.58	1.98	527.6	Flexural
	C-3	78.70	2.00	162.3	6.11	2.05	640.4	Flexural
	C-4	75.40	1.87	170.4	5.61	2.00	656.2	Flexural
	C-5	95.59	2.26	183.6	7.86	2.47	1031	Flexural
	C-6	110.2	2.62	205.9	10.40	2.97	1556	Flexural
Group D (a/d = 2.2)	D-0	69.79	1.96	114.8	5.33	1.72	415.8	Flexural
	D-1	72.35	2.12	132.5	5.84	1.75	509.6	Flexural
	D-2	75.46	2.06	145.6	5.79	1.82	534.0	Flexural
	D-3	80.50	2.14	156.6	6.13	1.86	616.8	Flexural
	D-4	76.22	1.97	162.0	5.63	1.86	555.2	Flexural
	D-5	90.50	2.26	178.2	8.16	2.61	1023	Compress.
	D-6	90.50	2.19	189.7	10.75	3.91	1524	Compress.

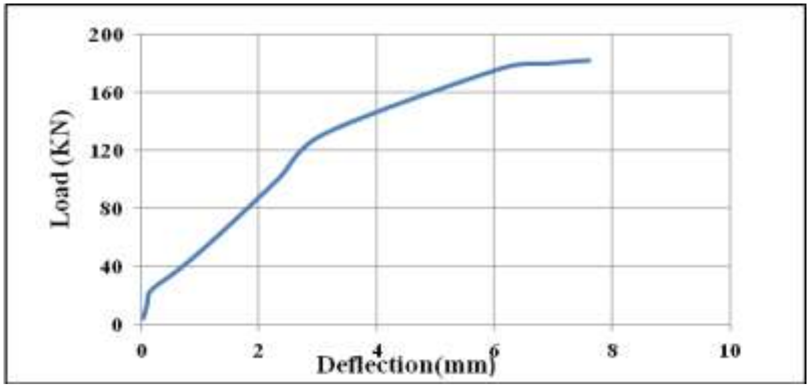


Figure (6): Load-Deflection Curve at Mid Span of Beam Model (A-٢) HSRC

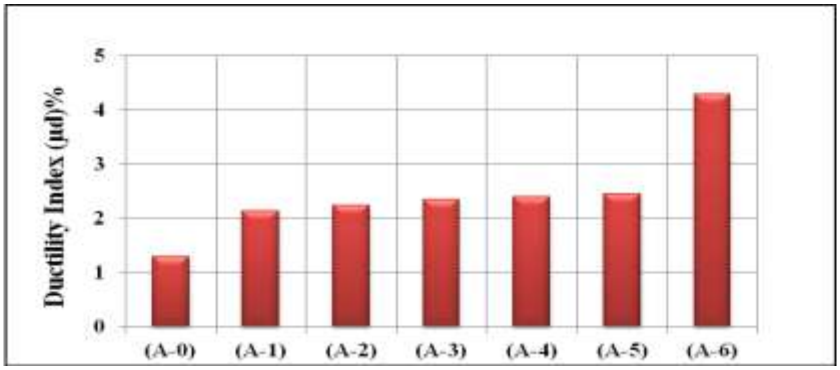


Figure (7): Ductility Index (μ_d) of Group (A) HSRC

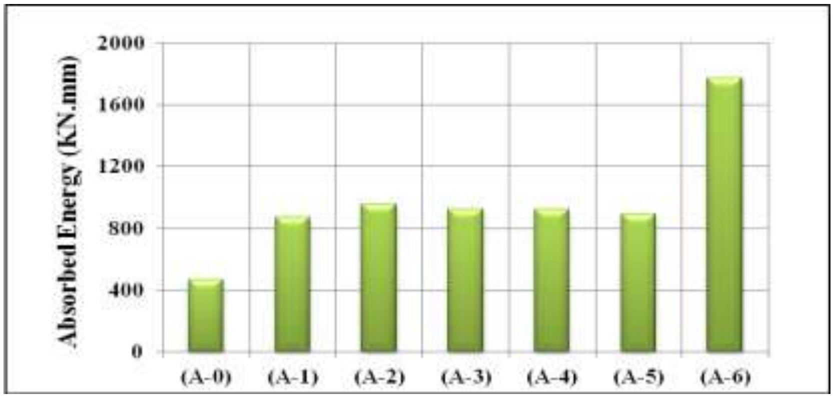


Figure (8): Absorbed Energy of Group (A) HSRC

Conclusions

Based on the results obtained from finite element analysis, the following can be concluded:

1. The ultimate load carrying capacity of all the beam models with steel fibers is higher when compared to the control beam.
2. For (NSRC) and (HSRC) beam models, The addition of steel fibers in concrete mixtures enhances the mechanical properties of concrete and provides crack propagation control . This property is attributed to the tensile stress transfer capability of the steel fibers across crack surfaces which known as crack-bridging.
3. For (NSRC) and (HSRC) beam models, the crack inclination observed in beam models without steel fibers was steeper than that observed in beams which had steel fibers, this means that the steel fibers act like shear reinforcement small diameter bars, when the fibers are closely spaced and randomly distributed.
4. The finite element results of (NSRC) beam models revealed that an increase up to 60.00% in ultimate load capacity can be achieved by using longitudinal reinforcement ratio equal to 2.20% compared to a ratio of 1.00%.
5. For (NSRC) beam models with steel fiber at one third of span from each side the load carrying capacity increased until steel fiber content 1.50% but with increasing fiber content to 2.00% load carrying capacity decreased, this is because the tensile stress exceeds the concrete tensile strength between previously formed cracks and a tensile force of sufficient magnitude to form an additional crack between two existing cracks can no longer be transferred by bond from steel fiber to concrete.
6. For (NSRC) beam model with zero fiber content and longitudinal tensile reinforcement ratio ($\rho\% = 2.23$) and beam model with 2.00% fiber content at lower half part and with ($\rho\% = 1.34$), the ultimate load capacity is almost same 220.0 KN. But beam model that containing fiber shows more ductile failure (flexural failure) than beam model without fiber. This is due to ability of adding fiber in enhancing shear and flexural capacity.
7. Steel fibers are more effective when high strength concrete is used, since the fiber reinforcement mechanisms increase with the increase of the concrete strength, as long as fiber rupture is avoided.
8. For (HSRC) beam models, the increase in the shear span to depth (a/d) ratio from 1.50 to 2.20 leads to a decrease in ultimate load capacity up to 28.00%.
9. For (HSRC) beam models, the presence of steel fibers transformed the mode of failure of the beam models into a more ductile one, especially for larger values of shear span to depth ratio (a/d) and catastrophic failures are avoided.
10. For (HSRC) beam models, the efficiency of adding discrete steel fiber increased with increasing shear span to depth ratio (a/d), The higher shear span to depth ratio (a/d) the higher number of cracks formed and as result more discrete steel fibers attribute in bridge and carry stresses crossing the crack faces, so a considerable ductility and absorbed energy can be achieved.

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