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The flexural behavior of nano concrete and high strength concrete using GFRP

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HIGHLIGHTS

- Structural behavior of Nano High Strength Concrete Beams Reinforced with GFRP bars.
- Structural behavior were studied in experimental & analytical manners.
- Nonlinear finite element analysis was performed using Ansys 14.5.

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ABSTRACT

The use of Nano-concrete (NC) is the most recent field of study in the concrete elements. So, this research was conducted in order to examine the flexural behavior of nano-concrete beams. Also, the effect of HSC reinforced with GFRP was examined. The effect of using glass fiber bars (GFRP) in reinforcement and the effect of it on concrete strain, the cracks patterns, number of cracks and the mode of failure was studied. The experimental program consists of eight RC beams; four NC beams and another four in HSC reinforcing using GFRP with different ratios. A non-linear finite element program corresponding to the experimental one was conducted using ANSYS 14.5 to verify the experimental results for each beam. Results indicated better agreement between experimental and analytical results.

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1. Introduction

Fiber reinforced polymer (FRP) bars are the most recent kind of FRP reinforcement used in structural engineering. The mechanical properties of basalt bars are alike to those of glass [1–6], so it can be believed that GFRP glass fiber reinforced concrete members can be considered according to the same design rules. However, GFRP reinforcement is considered as a new material, so the performance of GFRP reinforced concrete elements should still be examined.

The reinforcement with GFRP bars which has high tensile strength, high corrosion resistance, good insulation, and high fatigue resistance, high stiffness to weight and strength to weight ratios of these materials with respect to steel reinforcement. This made GFRP bars a challenging alternative to the conventional strengthening and repair materials [7,8].

Currently, the most active research areas dealing with cement and concrete are understanding of the use of Nano-size particles such as alumina and silica particles fume. Nano-concrete is the concrete with Portland cement micro-particles that are less than 500 Nano-meters [9–13]. The effect of using Nano-concrete is clear in crack patterns and width. In addition to using GFRP bars in reinforcement of beams with Nano-concrete mixes which used in the first group of experimental study.

Also, the increasing of the concrete strength effect directly in the increase of failure load. So, high strength concrete HSC mix was used in the experimental program in the second group. Using HSC mixes increase the failure loads without decreasing the cracks width, numbers, and length [14,15].

The aim of this study is to define the modes of failure, deflections, and ductility of simply supported GFRP RC beams using Nano-concrete and HSC mixes depending on the reinforcement ratio of GFRP bars with respect to the balanced ratio of steel. Results of experiments were compared with the results of the Non-linear Finite Element Analysis for the tested specimens [16].

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2. Experimental program

The beams were tested under two point-load machine. The machine capacity was 2000kN. The beam effective span was 1600 mm while the distance between the two loads points was 300 mm load. Linear variable displacement Transducer (LVDT) placed in the bottom of the beam at the mid-point to find the maximum deflection. The load was increased until the failure load of the beam. Load and displacement, strain of concrete and reinforcement were recorded. This was done in order to study the ultimate load carrying capacity, ultimate deflection, cracks patterns and mode of failure at collapse of the control beams, to compare their performance with group of beams with NC and GFRP bars as reinforcement and with the second group of HSC and GFRP reinforcement with different reinforcement ratios for two groups.

2.1. Experimental program content

The experimental program in this research consist of two group of 300 mm depth, 150 mm width and span of 1600 mm. Each group had four beams specimens while the first group used (NC) Nano-concrete of strength 50 MP_a and GFRP reinforcement. B1 is control specimen reinforced with reinforcing steel and NC mix. Specimens B1-1, B1-2 and B1-3 were reinforced with glass fiber bars GFRP with different ratios of 0.8 μ_b, $\mu_{b,}$ 1.2 μ_b respectively.

For the second group which used HSC high strength concrete of strength 60 MP_a. The first beam B2 of dimension 150x300x1600mm and steel reinforcement. For B2-1, B2-2 and B3-2 were with the same dimension and concrete mix but with different reinforcement ratios. B2-1 with GFRP bar reinforcement of ratio 0.8 μ_b but for B2-2 and B2-3 the ratio was μ_b and 1.2 μ_b as indicated in Table 1.

2.2. Concrete matrix

The concrete mix design was designed to get a compressive strength (f_{cu}) of 50 MPa and 60 MPa at 28 days. Mix properties are listed in Table 2.

2.3. Nano-silica

The material (Nano ESTEL), the trade name of Nano-silica which is a Nano-silica suspended in water, where the proportion of pure water is 30%. The Nano-particles has been dissolved with water to eliminate the danger that nanoparticles can cause to humans and the environment when used. The addition of Nano-silica for the concrete mix lead to better bond between aggregates and cement paste to increase the work surface also, improves the toughness, shear, tensile strength and flexural strength of concrete. 1.6 L/m^3 of Nano-ESTEL was added to the concrete mix. The following Table 3 and Fig. 1 showing the physical and chemical properties of the nanoparticles used in the research.

2.4. GFRP bars

The reason for using GFRP in the placement of conventional steel bars was as a result of strength capacity. Also, its resistance to coorrosion. These properties increase the capacities of beams reinforced using GFRP bars. The used bars were locally manufactured as shown in Fig. 2 and tested as in Fig. 3 to decrease its cost with high effect in prorerties. Table 4 indicate the obtained tensile strength for each diameter from GFRP bars.

2.5. Test setup

All beams were tested under two-point load testing machine of maximum capacity of 2000kN. The beams effective span was 1600 mm and the distance between the two points of applied load was 300 mm as shown in Figs. 4 & 5. This is to obtain the maximum flexural load. Also, LVDT was used to measure the maximum

Table 3
Properties of Nano-silica used.

Properties	Descriptions
Color	Light
Adour	Odorless
Physical state	Dispersion of a solid in a liquid
Solubility	Soluble in water
Dynamic viscosity at 20 C^0	6–8 MPa
Evaporation rate	N.D.
pH	9.5 to 10.4
Boiling point	$100C^0$
Melting point	$0c^0$
Flash point	Not flammable
Upper/lower explosion limit	Product is not explosive
Self–ignition temperature	Product is not self-igniting
Vapor pressure	32 hPa at $25c^0$
Specific gravity	1.1–1.3 g/cm^3 at $20c^0$

Table 1
Beams specimens descriptions.

Series	Reinforcing type	Specimen Designation	Reinforcement Details			The reinforcement ratio (%)
			Tension Reinf.	Compression Reinf.	Stirrups	
Group I (NC)	steel	B1 (NC)	2 φ12	2 φ 10	φ8@145	0.60
		B1-1	2 φ 8	2 φ 8	φ8@145	0.8μb
	GFRP	B1-2	2 φ10	2 φ 8	φ8@145	μb
		B1-3	2 φ12	2 φ 8	φ8@145	1.2μb
Group II (HSC)	steel	B2 (HSC)	2 φ12	2 φ 8	φ8@145	0.60
	GFRP	B2-1	2 φ 8	2 φ 10	φ8@145	0.8μb
		B2-2	2 φ10	2 φ 8	φ8@145	μb
		B2-3	2 φ12	2 φ 8	φ 8@145	1.2μb

Table 2
Concrete mix design.

Item	Cement (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Water (kg/m^3)	Silica Fume (kg/m^3)	Nano-Silica (L/m^3)	Super plasticizer (kg/m^3)
Per m^3 of concrete (50 MPa)	325	1250	640	165	50	1.6	4.5
Per m^3 of concrete (60 MPa)	600	1100	550	140	60	——	16

Fig. 1. Nano-silica "Nano ESTEL" used in concrete mix.

deflections which applied at mid span of tested beams. Load was effective at 15kN increments on the tested specimens. The load was increased till failure load and maximum displacements. Load deflection relationship were recorded by a computerized data acquisition system. Crack pattern was also observed at each loading stages.

3. Results and discussion

The tested specimens were divided into two groups 1 & 2. The first tested beams poured using Nano-concrete mixes for beams reinforced with GFRP bars. The beams behavior was observed from the first crack appeared till failure. The first crack occurred corresponding to its load was recorded and the deflection at first crack also recorded. The second group was the beams reinforced using GFRP bars with high strength concrete of characteristic strength of 60 MPa. Also, the cracks propagation was observed with naked eye and the deflection was recorded with LVDT at the middle span of the beam.

3.1. Mode of failure

The failure mode for the tested reinforced concrete beams were observed by naked eyes. This mode of failure was varied between flexural failures especially for beams reinforced using steel bars of B1 and B2. For specimens B1-1, B1-2 B2-1 and B2-2 the failure was tension failure but accompanied with sudden failure in GFRP bars. It occurs suddenly which refer to the failure mechanism of fiber bars so, it is GFRP bars failure. El-Nemr [7], recorded similar mode of failure in specimens reinforced by FRP bars. Table 5 represent this mode of failure, while the failure mode of specimen B1 and B2 was tension failure while it reinforced using steel bars. The concrete crushing occurs in the specimens of reinforced ratio of 1.2μb. Although this compression failure the tension cracks occurs until the concrete crushed due to the high tensile strength of GFRP bars.

Table 4
Tensile strength for steel RFT and GFRP bars.

Diameter (mm)	Tensile strength GFRP (MP_a)	Tensile strength Steel (MP_a)	% of increase In tensile strength
8.0	482.24	360.0	134.0
10.0	636.37	520.0	122.4
12.0	745.64	520.0	143.4

a) b) c)

Fig. 2. Locally manufactured GFRP bars, a) 10 mm Ribbed GFRP bars. b) 12 mm Ribbed GFRP bars. c) Smooth GFRP bars.

a) b)

Fig. 3. Sample of testing the tensile strength of GFRP bars a) pasting strain gauge on bars, b) tensile test for GFRP bars.

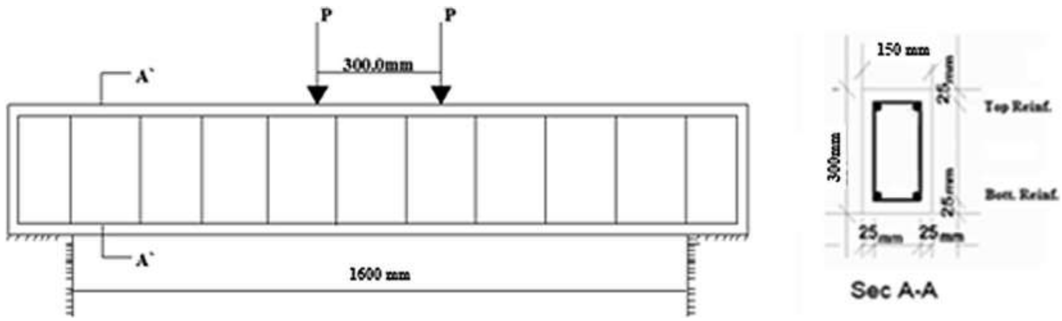

Fig. 4. Typical Beams Geometry and reinforcement details.

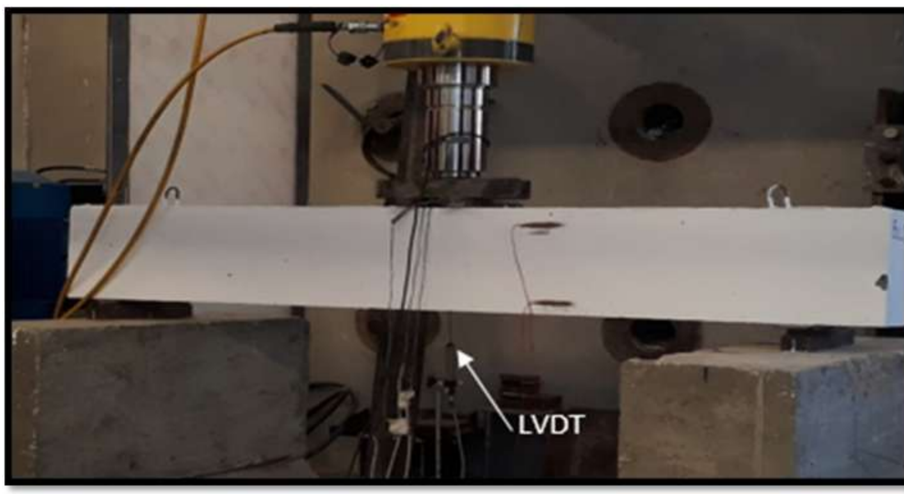

Fig. 5. Test Set up.

Table 5
Experimental Failure Load and Mode of Failure.

series	Reinforcing type	The reinforcement steel ratio (%)	Mode of failure	Experimental Failure load (kN)	Frist crack Load (kN)
Group I (NC)	steel	0.60	T.F	58.0	24.0
	GFRP	0.8µb	GFRP.F	37.5	20.0
	GFRP	µb	GFRP.F	47.4	23.0
	GFRP	1.2µb	C.C	71.0	26.0
Group II (HSC)	STEEL	0.60	T.F	63.0	20.0
	GFRP	0.8µb	GFRP.F	48.5	18.0
	GFRP	µb	GFRP.F	54.0	21.0
	GFRP	1.2µb	C.C	73.5	23.0

T.F: Tension Failure in steel bars, GFRP.F: GFRP bars failure, C.C: compression failure in concrete.

3.2. Crack patterns and width

The first cracks occurred in all specimens approximately in the tension zone at the middle of the beams. The other cracks occurred as tension cracks as shown in Fig. 6. For specimens beam B1 and B2 showing tension but there is difference in cracks numbers. The cracks in B1 are less in number and width due to the Nano silica used in concrete mix. But in B2 which use high strength concrete mix the cracks propagate and width increase as normal concrete but at high values of failure loads. The first crack of B1 was observed at 24.0 kN and at 20.0 kN for B2. By the same mechanism of cracks appear for the other specimens, the first cracks appear at 20.0 kN, 23.0 kN and 26.0 kN for B1-1, B1-2 and B1-3 respectively as they all reinforced using 0.8µb, µb and 1.2 µb as reinforcing ratio of GFRP and with Nano concrete mix of strength 50 MPa.

The observed cracks in the second group of high strength concrete and reinforced using GFRP bars with different ratios for B2-1, B2-2 and B2-3 of 0.8µb, µb and 1.2 µb as of GFRP and with HSC concrete mix of strength 60 MP_a. The first cracks observed at 18.0 kN, 21.0 kN and 23.0 kN respectively as shown in Table 5 and Figs. 6, 7.

At the final stages of loading which leads to failure, the cracks increased in numbers and width to lead to failure. The concrete type as Nano concrete and the reinforcement ratio have the main parameter to decrease the width of cracks for group 1 compared to group 2.

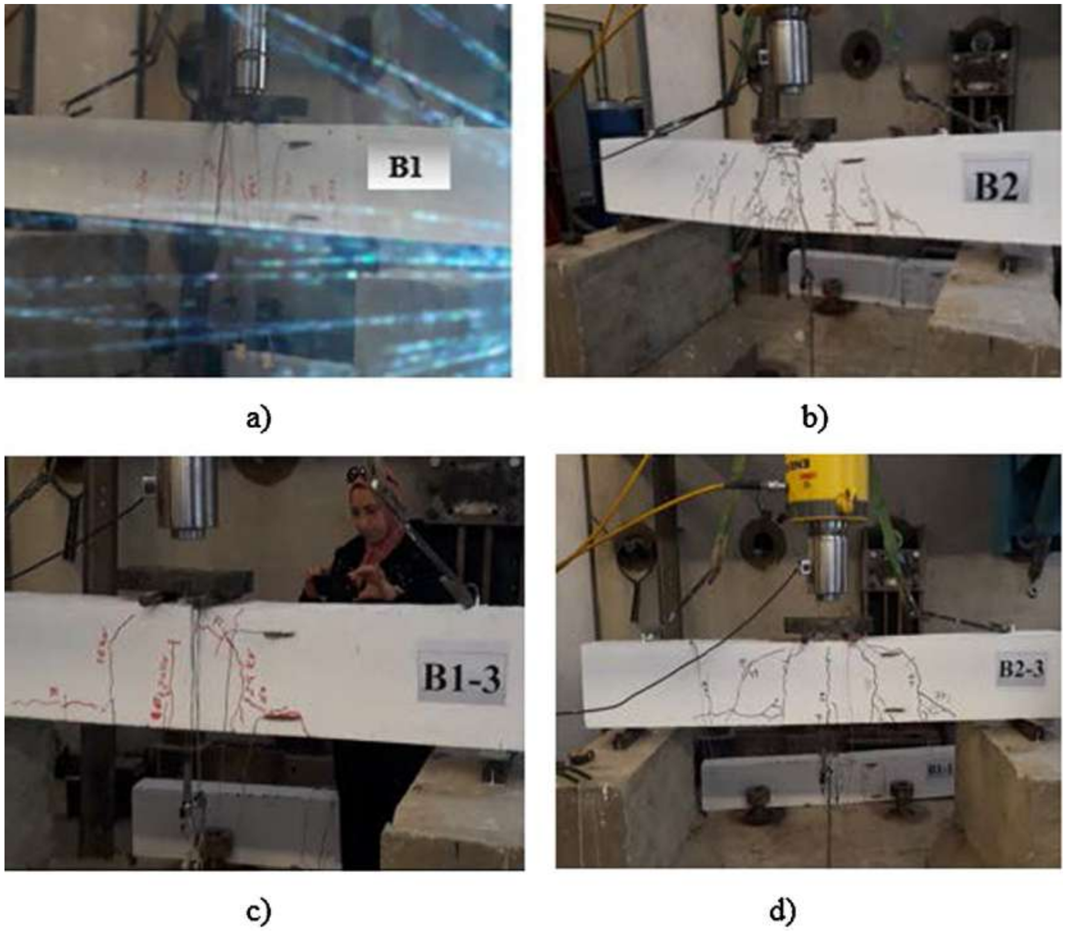

Fig. 6. Crack patterns for different beams, a) crack pattern of B1 for Nano-concrete beam, b) crack pattern of B2 of high strength concrete, c) sample of crack pattern of Nano-concrete beam reinforced with GFRP bars, d) sample of crack pattern of HSC beam reinforced with GFRP bars.

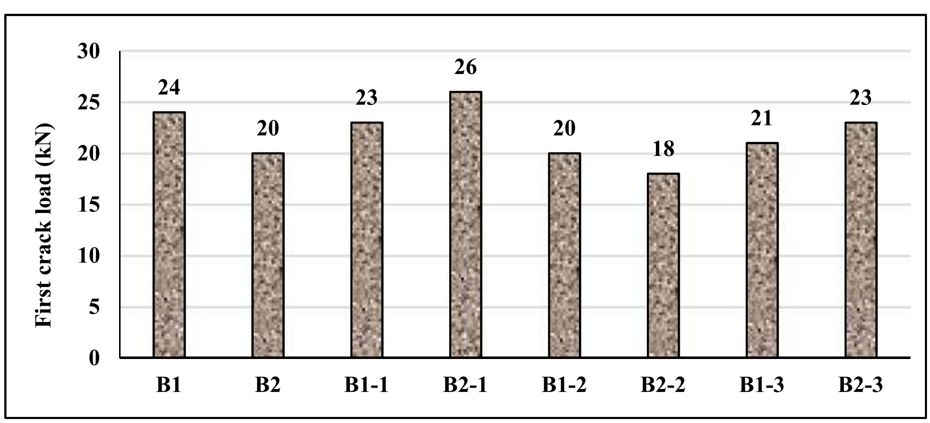

Fig. 7. Comparison between first crack loads for tested beams.

3.3. Ultimate failure load and ultimate deflection

The ultimate failure load and its corresponding deflection were recorded in Table 6 and Figs. 7–9. The deflection was recorded using LVDT at the mid span verse to the corresponding experimental loads. For the first group which used Nano concrete in its mix and GFRP bars in reinforcement, the deflection was less than in the second group. Especially, the concrete strength in second group was 60 MP_a and 50 MP_a in the first group. For B1 the failure load was 58.0 kN with deflection of 2.65 mm while it was reinforced using steel bars of ratio 0.6% and Nano concrete. For the other specimens B1-1, B1-2 and B1-3 which reinforced with 0.8μb, μb and 1.2μb respectively and used Nano concrete mix the ultimate failure loads were 37.5 kN, 47.4 kN and 71.0 kN respectively. Its deflections were 3.2 mm, 12.2 mm and 17.15 mm respectively. It was observed that using Nano particles decrease the numbers and width of cracks with respect to the other specimens which agreed with Raki, L. and *et al.* [11].

For the group of high concrete strength of 60 MPa, the failure load of B2 was 63.0 kN which increase with approximately 9.0%

Table 6
Experimental test results.

Series	Specimen	The reinforcement steel ratio (%)	First crack load (kN)	Ultimate failure load (kN)	Deflection at first crack load, mm	Deflection at ultimate load, mm	Ductility index (%)
Group I	B1	0.60	24.0	58.0	0.95	2.65	35.9
	B1-1	0.8μb	20.0	37.5	1.15	3.20	36.0
	B1-2	μb	23.0	47.4	2.70	12.50	21.6
	B1-3	1.2μb	26.0	71.0	3.25	17.15	18.9
Group II	B2	0.60	20.0	63.0	1.10	3.15	34.9
	B2-1	0.8μb	18.0	48.5	1.35	5.56	24.3
	B2-2	μb	21.0	54.0	2.40	9.17	26.2
	B2-3	1.2μb	23.0	73.5	4.10	15.80	25.9

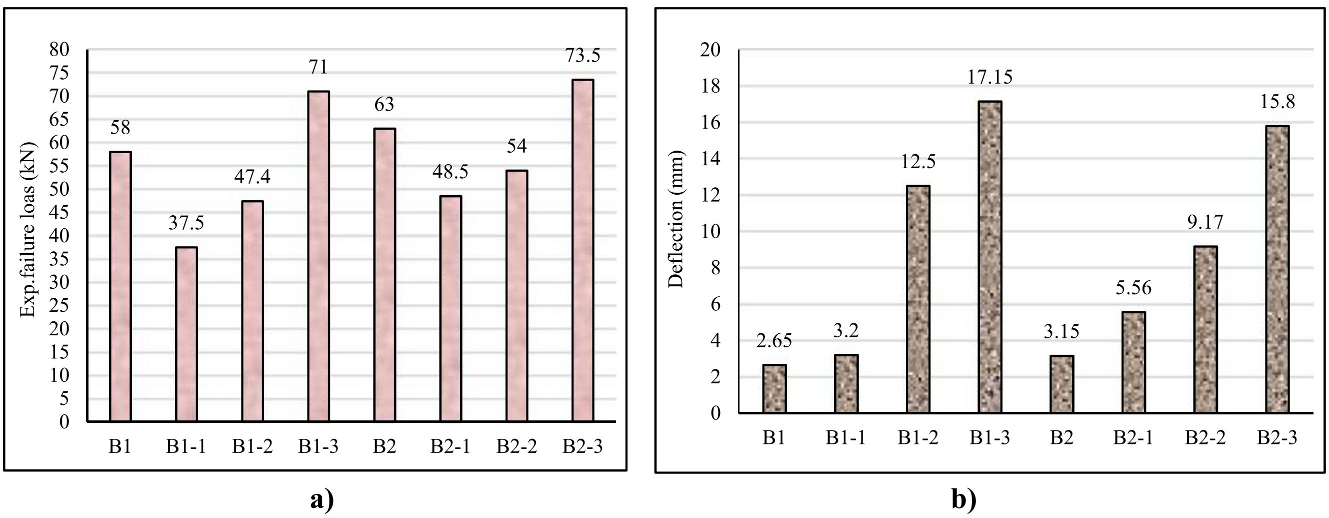

Fig. 8. Comparison between experimental results, a) ultimate load, b) ultimate deflection.

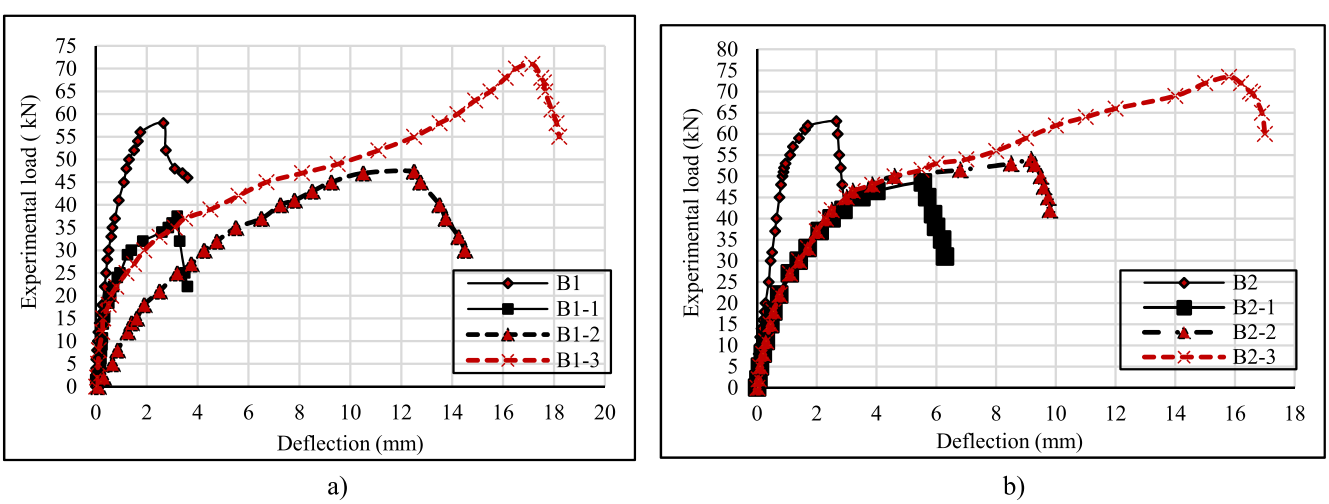

Fig. 9. Load deflection curve; a) first group; b) second group.

compared to B1. Also, the deflection recorded 3.15 mm due to increase in failure load and the absence of Nano particles. For the specimens reinforced using the GFRP bars with different ratio recorded a different value in failure loads which they were 48.5 kN, 54.0 kN and 73.5 kN for B2-1, B2-23 and B2-3 respectively verse to deflection of 5.56 mm, 9.17 mm and 15.8 mm as in Table 6. This behavior of increasing in failure load was due to the effect of concrete strength and the tensile strength of GFRP bars which agreed with B.L.Karihaloo D. ShanmugaPriya [14].

3.4. Ductility response

The ratio between the first crack loads to the failure loads can be defined as the ductility. The ductility represents the behavior

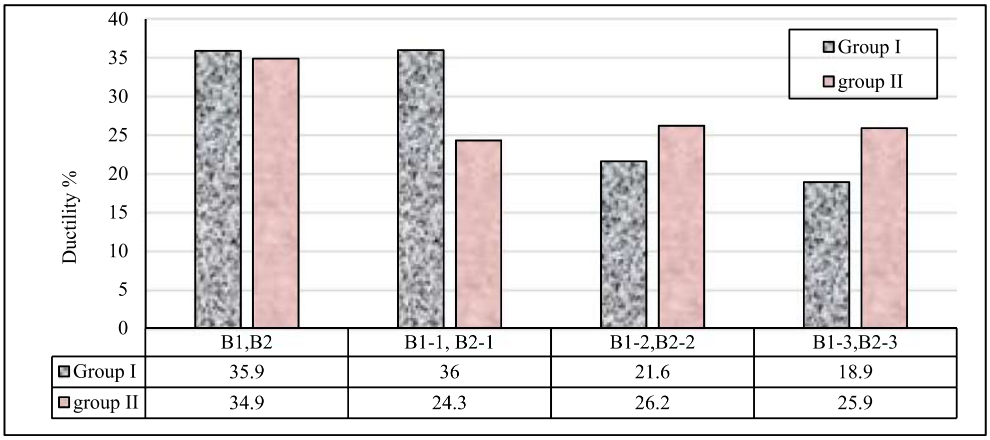

Fig. 10. Comparison between ductility ratios of tested beams.

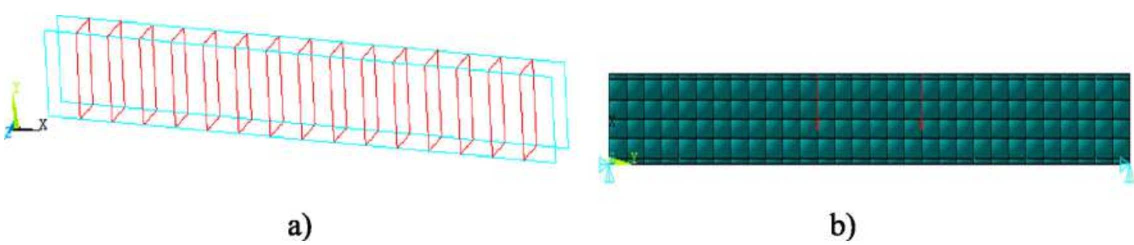

Fig. 11. Representation of tested beam, a) reinforcing bars as link 64, b) solid 65 for concrete.

Table 7
NLFEA Analytical Results.

Series	Specimen	The reinforcement steel ratio (%)	First crack load (kN)	Ultimate NLFE failure load (kN)	Deflection at first crack load, mm	Deflection at ultimate load, mm	Ductility index (%)
Group I	B1	0.60	15.0	49.3	0.45	2.25	20.0
	B1-1	0.8μb	15.0	33.4	0.85	2.84	29.9
	B1-2	μb	15.0	37.5	1.25	9.87	12.7
	B1-3	1.2μb	15.0	56.8	1.75	13.72	12.7
Group II	B2	0.60	18.0	53.6	0.55	2.25	24.4
	B2-1	0.8μb	18.0	38.3	0.95	4.39	21.6
	B2-2	μb	18.0	48.6	1.45	8.25	17.6
	B2-3	1.2μb	18.0	62.5	3.25	13.43	24.2

Table 8
Comparison between Experimental and NLFEA.

Group	Specimen Symbol	Ultimate Failure load, Pult (kN)		Deflection at ultimate load, Δult (mm)		Pult NLFEA/Pult Exp.	Δult NLFE /Δult Exp.
		NLFEA	EXP.	NLFEA	EXP.		
Group I (NC)	B1	49.3	58.0	2.25	2.65	0.85	0.84
	B1-1	33.4	37.5	2.84	3.20	0.89	0.88
	B1-2	37.5	47.4	9.87	12.50	0.79	0.78
	B1-3	56.8	71.0	13.72	17.15	0.80	0.80
Group II (HSC)	B2	53.6	63.0	2.25	3.15	0.85	0.71
	B2- 1	38.3	48.5	4.39	5.56	0.78	0.79
	B2-2	48.6	54.0	8.25	9.17	0.90	0.89
	B2-3	62.5	73.5	13.43	15.80	0.85	0.85
Average						0.84	0.82

of the specimens due to existing of steel or FRP reinforcement. The difference between steel and FRP reinforcement is that steel exhibit yielding to large amount of ductility but FRP does not exhibit the same behavior. The ductility obtained from specimens reinforced using GFRP bars related to the high experimental failure load to the load of the first crack. Fig. 10 and Table 6 show a comparison between the obtained ductility for each specimens. For the group which used Nano concrete and strength of 50 MPa, the ductility ratio was varied from 18.9% to 35.9%. For specimens of the second group, the ductility was varied from 24.3% to 34.9%. It was observed that the highest ductility behavior was in beams reinforced using steel bars.

4. Non-Linear finite element analysis

NLFEA non-linear finite element analysis was done to simulate the concrete beams reinforced with GFRP bars with the experimental results. The ANSYS software [17] was used to verify this purpose. The failure load, deflection, first cracks, total cracks and ductility are the main parameters which will be discussed in the finite element program. Therefore, an agreement between the obtained NLFEA results and the experimental results which verify the model of ANSYS. The program for the beams which used in experimental test is the same for what in NLFEA. For representing the elements of the experimental tested beams, solid 65 is used for this purpose. Link 64 spare was used to represent the reinforcing bars for steel and basalt bars as shown in Fig. 11.

4.1. Analytical ultimate failure load

Table 7 indicate the analytical failure loads for the beams and its corresponding deflections. The deflection was recorded using the obtained results from ANSYS results at the mid span verse to the corresponding experimental loads. It was observed that the load–deflection curves for specimens reinforced using GFRP bars was agreed with the behavior of experimental results either for Nano concrete specimens or HSC beams. For the group which has Nano concrete of strength equals to 50 MPa, the failure loads were 49.3 kN for B1 of Nano concrete and reinforced using steel bars.

For specimens B1-1, B1-2 andB1-3, the failure loads were 33.4 kN, 37.5 kN and 56.8 kN respectively. Observed the increase in failure load for beams reinforced using GFRP bars accompanied with experimental results epically for B1-3 which reinforced using the same diameter of bars but in GFRP.

The second beams group which has HSC of strength 60 MPa, the obtained results from NLFEA was as shown in table 7. For B2 the failure load was 53.6 KN but the failure loads were 38.3 kN, 48.6 kN and 62.5 kN for B2-1, B2-2 and B2-3 respectively. This increase in failure loads for the specimens reinforced using GFRP bars is due to the high tensile strength of used bars with respect to the steel bars.

4.2. Deflection and the mode of failure

The specimen's deflection which simulated in NLFEA was recorded to compare it with experimental deflection. The results obtained from NLFEA program were presented in Table 7. The deflections for group 1 which used Nano concrete were 2.25 mm, 2.84 mm, 9.87 mm and 13.72 mm for B1, B1-1, B1-2 and B1-3 respectively. Also, the deflection of second group was presented in Table 7. The deflection recorded 2.25 mm, 4.39 mm, 8.25 mm and 13.43 mm for B2, B2-1, B2-2 and B2-3 respectively with an average of 7.08 mm. These results show the behavior of concrete beams with Nano-concrete and GFRP reinforcement and HSC beams behavior with GFRP reinforcement. Using HSC is effective in increasing the failure load capacity and decreasing the deflection with respect to Nano-concrete and normal concrete.

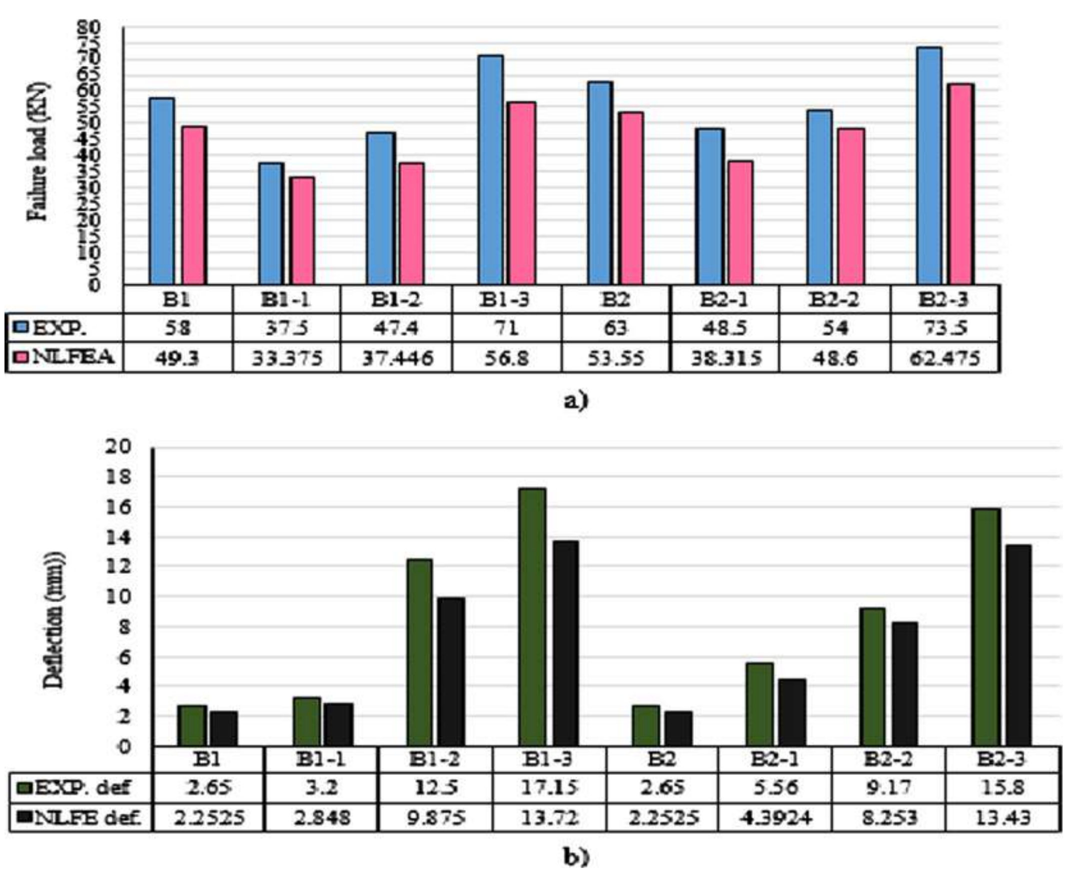

Fig. 12. Comparasions between experimental and analytical results; a) Failure load; b) ultimate deflection.

5. Comparison between experimental and NLFEA results

There are eight finite element models were compared with eight experimental specimens in term of ultimate load, ultimate deflection and obtained ductility.

Satisfied agreement between the experimental and NLFEA failure load as shown in Table 8 and Fig. 12. It was found that Pu *NLFEA*/Pu exp. with a ratio of 0.85 for B1 in the first group and B2 in the second group which shows good agreement between the two obtained results. For beams B1-1, B1-2 and B1-3 the ratios of Pu *NLFEA*/Pu exp. were 0.89, 0.79 and 0.80 respectively. For beams B2-1, B2-2 and B2-3, Pu *NLFEA*/Pu exp. ratios were 0.78, 0.90 and 0.85 respectively. The NLFE analysis showed good correspondence with experimental results with an average ratio of 0.84 in failure load. The average in agreement between NLFEA deflection and experimental one was 0.82.

5.1. Ultimate loads

Fairly agreement between the experimental and NLFEA failure load as showed in Table 8 and Fig. (12-a), Fig. 13. It was found that Pu *NLFEA*/Pu exp. with a ratio of 0.85 for B1 in the first group and B2 in the second group which showed good agreement between the two obtained results. For beams B1-1, B1-2 and B1-3 the ratios of Pu *NLFEA*/Pu exp. were 0.89, 0.79 and 0.80 respectively. For beams B2-1, B2-2 and B2-3, Pu *NLFEA*/Pu exp. ratios were 0.78, 0.90 and 0.85 respectively.

5.2. Ultimate deflections

Fig. (12-b), Fig. 13, Fig. 14 and Table 8 showed comparison between deflection from experimental test and NLFEA. Fig. 13 showed the agreement in behavior between the two obtained results. For the deflection of beams B1-1, B1-2 and B1-3, the ratios of Δult *NLFEA*/Δult exp. were 0.88, 0.78 and 0.80 respectively. For beams B2-1, B2-2 and B2-3, the ratios Δult *NLFEA*/Δult exp were 0.79, 0.89 and 0.85 respectively showing good agreement. Fig. 13 showed comparisons between experimental and NLFEA load deflection curves for all tested specimens. As a result of previous, the analytical models provided an acceptable load deflection response.

5.3. Cracks pattern

Crack pattern obtained from experimental test and NLFEA for all beams exhibited approximately similar patterns of crack propagation in flexural failure. Fig. 15 indicate comparison between those obtained. These cracks started at the middle of the beams and became diagonal and grew toward the loading points. After that it increase in length and width till failure. In the first group which use Nano concrete mix, it was noticed that number of cracks is less than in the HSC mix in the second group as shown in Fig. 15-b. the NLFEA results was compatible with the experimental results that is agreed with El-Sayed [18,19].

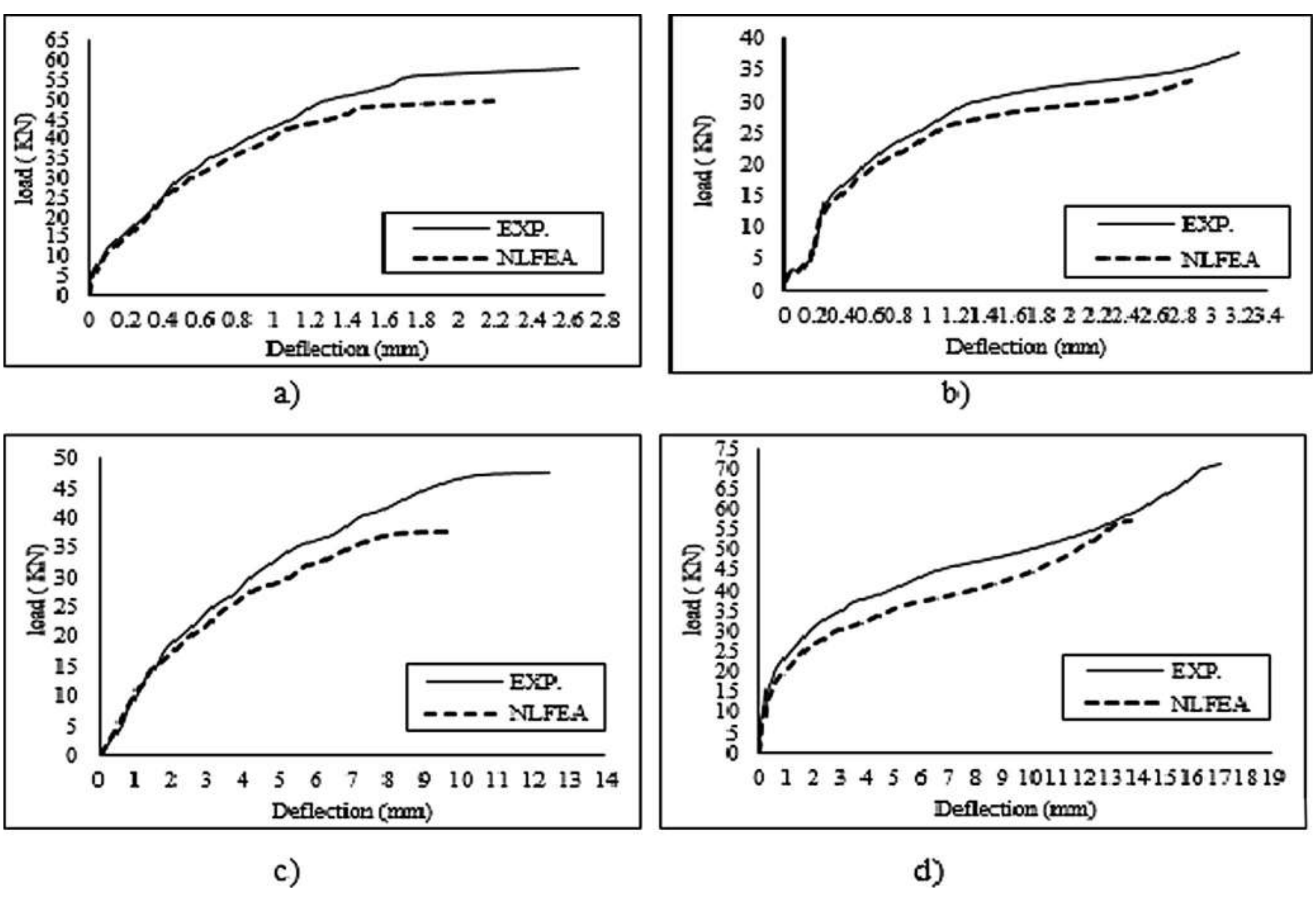

Fig. 13. Comparasions between experimental and analytical load–deflection curves; a) B1; b) B1-1; c) B1-2; d) B1-3.

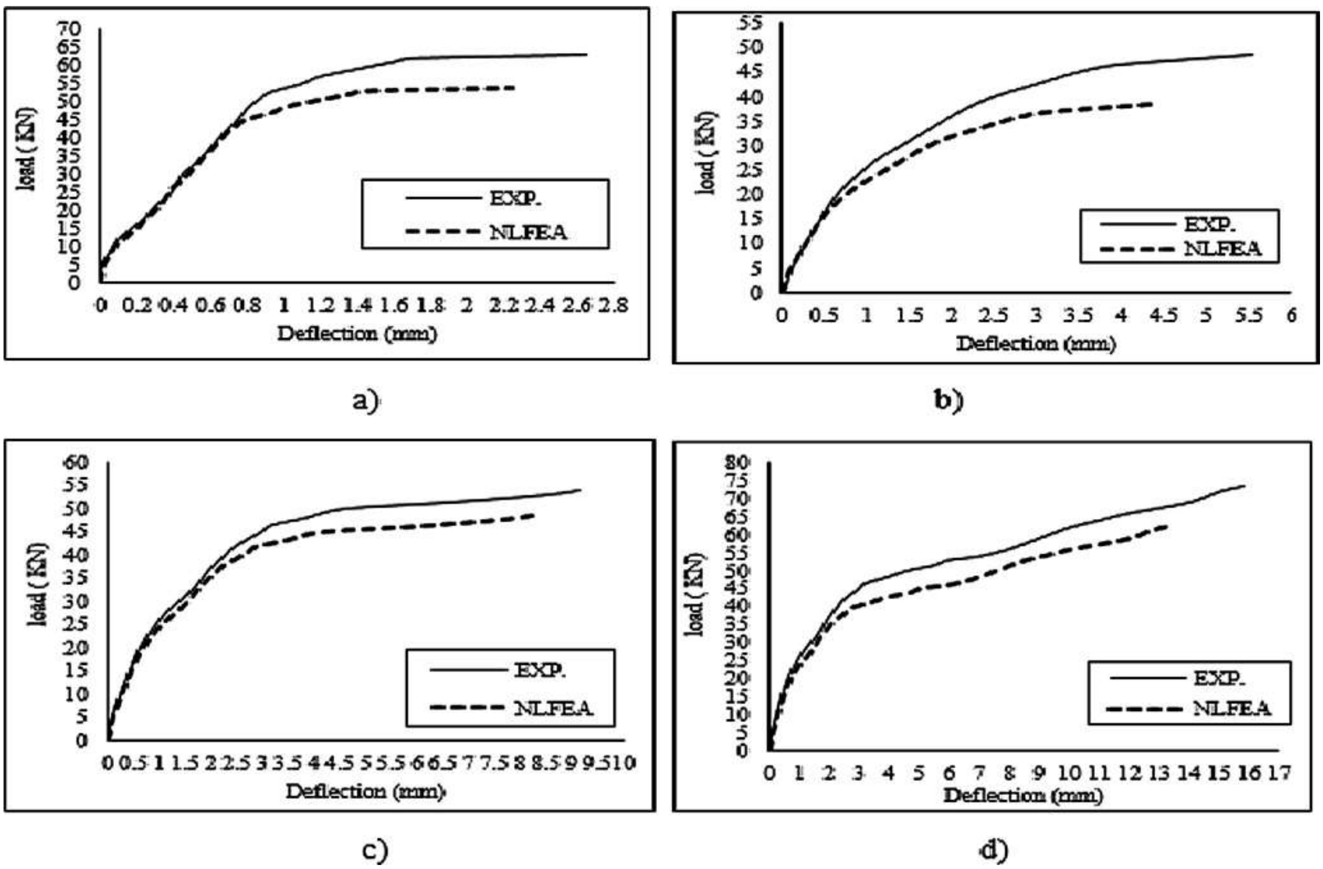

Fig. 14. Comparasions between experimental and analytical load–deflection curves; a) B2; b) B2-1; c) B2-2; d) B2-3.

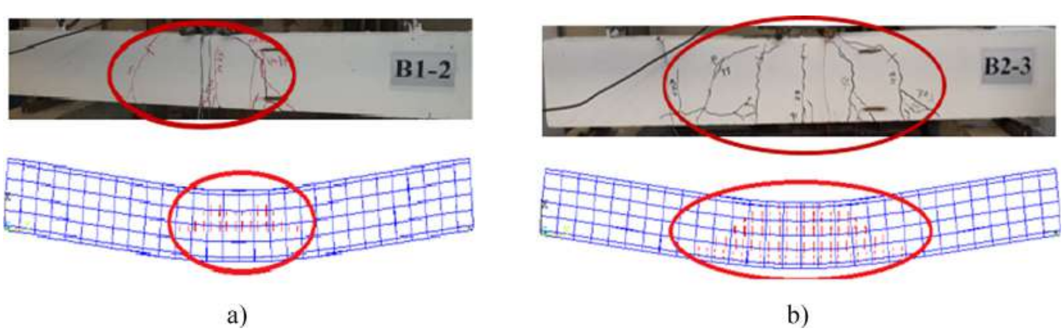

Fig. 15. Crack pattern for examined beams; a) Sample of Nano-concrete beams cracks; b) Sample of HSC beams cracks.

6. Conclusion

The current research investigated the flexural behavior of concrete beams reinforced with glass fiber reinforced polymer GFRP bars. This investigation shows the advantage GFRP bars in reinforcement with respect to steel reinforcement in either Nano concrete or high strength concrete mixes. Comparison of the experimental results with the values obtained from analytical models resulted in the following conclusions:

1- The GFRP bars exhibit mechanical failure mechanism as FRP polymers which take the brittle failure mode if it reaches its ultimate capacity.
2- The Nano-concrete mix which used in first group has no effect in increasing the concrete strength but it enhanced the behavior of beam's cracks in flexure, decrease its numbers and width.
3- Using HSC in the beams specimens was effect in increasing the failure load capacity and enhanced its flexural behavior with respect to control specimens.
4- The loads deflection curves were semi bilinear for all GFRP reinforced beams. The first part of the curve up to cracking represents the behavior of the un-cracked beams. The second part represents the behavior of the cracked beams with reduced stiffness.
5- Using GFRP bars in high strength concrete remain with larger ductility with respect to the specimens with concrete strength. Regardless, the ductility of specimens reinforced with steel bars maintain high ductility.
6- The failure loads of reinforced beams with GFRP bars increased with respect to beams reinforced using steel bars.

The ratio of increase in failure load is varied between 15.0% and 16.0% in the tested specimens.

7- The cracks were decreased in length and width due to use of GFRP bars as shown in Fig. 15.

8- NLFEA using ANSYS 14.5 gives a computable result in failure loads, deflection and the crack pattern. The average agreements between $P_{ult\ NLFEA}$ / $P_{ult\ Exp}$ and $\Delta_{ult\ NLFE}$ / $\Delta_{ult\ Exp}$ is about 0.84 and 0.82 respectively.

CRediT authorship contribution statement

Abeer M. Erfan: Conceptualization, Formal analysis, Validation, Visualization, Writing - original draft, Investigation, Supervision, Writing - review & editing. **Hossam E. Hassan:** Writing - original draft, Investigation, Data curation, Supervision, Writing - review & editing. **Khalil M. Hatab:** Writing - original draft, Conceptualization, Data curation, Formal analysis, Funding acquisition, Resources. **Taha A. El-Sayed:** Writing - original draft, Methodology, Project administration, Software, Supervision, Validation, Visualization, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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