Shear Behavior of Reinforced Concrete Beams Contained Nano Silica and Strengthening by Epoxy Injection

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Abstract - *The use of Nano silica as an additive material in manufacturing concrete is a new technology. Tests have shown that this material enhances the mechanical properties of hardened concrete. The addition of this material increases density, reduces porosity and bleeding, and improves the bond between cement matrix and aggregates. Thus, some concrete with high compressive strengths can be produced when using Nano-silica. Pertaining to the shear failure of concrete members, it is well known that when principal tensile stresses exceed the tensile strength of concrete, diagonal cracks occur in the shear span. Some of the existing reinforced concrete structures may require strengthening or repairing to increase their structural performance. It has been reinforced using an internal epoxy injection, where epoxy is used as a strong material with high pressure strength and high cohesion with concrete. This study presents shear behavior of reinforced concrete beams contained nano silica and strengthening by epoxy injection. Different concrete mixtures were using nano-silica (0,2, 4, 6%) and different cement content to obtain concrete compressive strength of 30, 45, 60 Mpa. Eight mixes were used to inspect concrete beams. Beams were strengthening by internally injected epoxy in shear zone. Through this study, it is found that beams with 4% nano silica, showed the best results in terms of ultimate load and ductility. The use of injected kemapoxy103 increased the ultimate load and absorbed energy significant in most case. The results showed that the injection of Kemapoxy 103 increased the ultimate load and absorbed energy up to 7.4% and 38.6%, respectively.*

Key Words: Nano silica; Epoxy injection; Shear strengthening; Ductility

1. INTRODUCTION

Many existing concrete structures around the world are in desperate need of rehabilitation, rebuilding, and repair due to deterioration caused by various factors such as corrosion, failure of bonding between joints of girder columns, increased service loads, and so on. Which leads to cracking, and the loss of strength, skew, and so on, that the need for effective rehabilitation and techniques of existing concrete structures led to structural strength research and development. Although most concrete structures have performed well in recent years, several issues have emerged because of poor material quality, inaccurate specifications, inappropriate design, construction faults, or extreme environmental conditions. Cracks may represent the entire extent of damage, or they may suggest larger difficulties. They may indicate just, or they may signify serious structural distress or lack of durability. Its significance is determined on the type of structure and the nature of the crack. Various methods for adjusting cracks in reinforced concrete beams. [1] To patch holes in a structure, you will need a fix that is both elastomeric and chemically resistant. The goal of this project is to strengthen the girder by modifying reinforced concrete beams and improving their strength.

Shear failure in concrete is known to be brittle and disastrous. In usual structural design, shear is accounted for by providing shear reinforcement such as stirrups in beams, Sometimes the shear reinforcement may be less than sufficient if the loading configuration were different from that predicted during design, such as during earthquake or at critical section reinforcement conjunctions. Fibers are effective shear reinforcement, its increased shear strength and ultimately results in ductile flexure failures. Pertaining to the shear failure of concrete members, it is well known that when principal tensile stresses exceed the tensile strength of concrete, diagonal cracks occur in the shear span. The use of discontinuous, randomly oriented fibers has long been recognized to provide post-cracking tensile strength to concrete. [2]

Nanomaterials are fundamental to both nanoscience and nanotechnology. Nanostructure science and technology is a broad and interdisciplinary field of research and development that has exploded in popularity over the last few years all over the world. It has the potential to transform the way materials and products are made, as well as the variety and kind of functions available. It already has a large commercial influence, which will undoubtedly growing the future. [3]

Nano-silica has a great impact on the mechanical properties of concrete. The addition of this material increases density, reduces porosity and bleeding, and improves the bond between cement matrix and aggregates. Thus, some concrete with high compressive and flexural strengths can be produced when using Nano-silica. [4]

Al Ghabban et al, conducted a test on 13 prisms to test the effect of using Nanosilica on the mechanical properties and flowability of concrete. The main parameters were the change in cement content and the Nanosilica content (0%, 1%, 2%, 3%, and 4%) in the concrete mix. The test results concluded that the optimum percentage of Nanosilica in the concrete mix was 4% to achieve a better performance. [5]

Tavakoli et al, conducted a test on nine cubic molds and studied the effect of Nanosilica on concrete properties, the test results also concluded that the best behavior was obtained with the use of 4% Nanosilica, then the mechanical properties lowered as the percentage of Nanosilica was more than 4%.[6]. Repair is the process of restoring something to its original state after it has been damaged, deteriorated, or broken. Damaged buildings are repaired to restore their strength after a calamity.[7]

The act or process of faithfully representing the form, characteristics, and character of a property as it appeared at a specific moment in its history by removing features from previous periods and reconstructing missing features from the restoration period. [8]. H. Nikopour and M. Nehdi conducted a test on six RC girders to see if there is an effect, inject the FRP hybrid shear installation and the external epoxy into the RC beams. The test results concluded that the Crack injection with low viscosity epoxy increased the stiffness of all repaired RC beams. [9]

M. Venkata Rao et al, tested the reliability of concrete containing Nanolsilica. It was found that the use of 3% Nanosilica in concrete mix significantly increased the concrete resistance to cracks and permeability. However, increasing the amount of Nanosilica above a certain level can negatively affect the concrete performance. [10]. Rahul and Mini prepared a finite element model to test epoxy, acrylic resin modified mortar, hydraulic cement, and polyurethane in crack controlling. The results exhibited that epoxy-injected specimens can resist a considerably higher load than other materials, however the specimens had a brittle behaviour in failure. Unlike the polyurethane with the most ductile behavior. [11]

2. EXPERIMENTAL WORK

2.1. Materials

Ordinary Portland cement was utilized with the grade of 42.5 N/mm2. The employed cement's chemical and physical properties meet Egyptian Standard Specification (E.S.S. 4756-1/2009) (CEM I 42.5N). Fine sand with a specific gravity of 2.55 t/m3 was used. Crushed gravel with a maximum nominal size of 10 mm, specific gravity 2.64, and volume weight 1.567 t/m3 were used as coarse aggregates. In this study, Super Plasticizers (Addicrete BVF) was used as high-range water reducer.

2.2. Nano silica

Nano-silica used in this study is a white powder with the properties, which presented in Table 1.

Table -1: Nano-silica properties

Diameter of particles (nm)	Density (g/cm3)	Specific Surface (m2/g)	Purity Percentage
19	2.12	160	99.9

2.3. Kemapoxy 103

Kemapoxy 103 is an injection epoxy resin for concrete cracks that can fill the path of cracks even in the furthest points. It consists of two parts A and B with a mixing ratio of 2:1 for parts A: B. The injection operation was done through special pipes (pipeline) carrying the EPOXY from the pump to the concrete specimens.

2.4. Mix Design

In this experimental work, eight mixes were used to inspect concrete beams. The mix design and testing program were conducted in accordance with ECP. The required concrete compressive strength in this research was 30 Mpa, 45 Mpa, and 60 Mpa. Mix proportion by weight (kg/m3) of fresh concrete is given in Table 2.

Table -2: Nano-silica properties

Mix	Cement	Water	Fine Agg.	Coarse Agg.	Silica Fume (7.5%)	Super Plasticizer (3%)	Nano Silica
	Kg/m^3						
300-0%	270	135	657.4	1314.8	20.3	8.1	0
300-2%	270	135	656.1	1312.1	20.3	8.1	5.4
300-4%	270	135	654.7	1309.5	20.3	8.1	10.8
300-6%	270	135	653.4	1306.8	20.3	8.1	16.2
450-0%	369	140	625.2	1250.3	27.7	11.1	0
450-4%	369	140	621.6	1243.2	27.7	11.1	14.8
600-0%	467	150	593.2	1186.5	35.0	14.0	0.0
600-4%	467	150	588.6	1177.2	35.0	14.0	18.7

2.5. Details of Concrete Beams

Experimental program was carried out to investigate the influence and the effect of using Nano-Silica on the concrete compressive strength to obtain the optimum percentage with respect to the 7 and 28-day compressive strength. Experimental tests were carried out on a total number of fourteen reinforced concrete beams under static loading up to failure. The reinforcement of the tested beams was 3 Φ 12 at the bottom and 2 Φ 10 at the top with stirrups of Φ 8 mm @ 125mm as shown in figure 1, and figure 2, table 3.

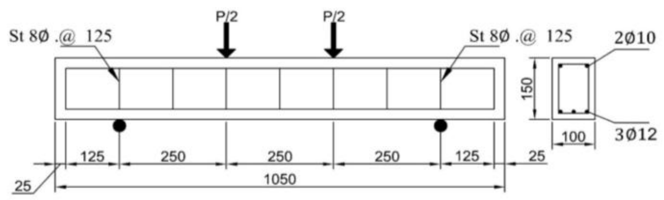


Fig -1: Test Specimens of Groups (1, 2, 3) (Reinforced concrete beam)

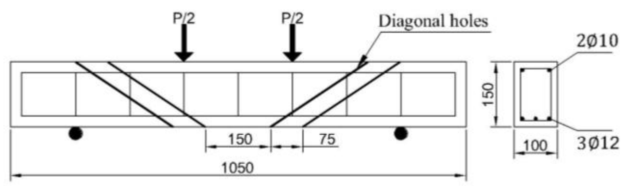


Fig -2: Test Specimens of Groups (4 and 5) (Reinforced concrete beam internally injected by epoxy)

Table -3: Strengthening and Repairing Scheme

Group no.	Beam ID	Nano Silica (%)	F_{cu} MPa	Epoxy
G1	B1-0-300	0	30	—
	B2-0-450		45	
	B3-0-600		60	
G2	B4-2-300	2	30	—
	B5-4-300	4		
	B6-6-300	6		
G3	B7-4-450	4	45	—
	B8-4-600		60	
G4	B9-0-300I	0	30	2 Hole
	B10-0-450I		45	2 Hole
	B11-0-600I		60	2 Hole
G5	B12-4-300I	4	30	2 Hole
	B13-4-450I		45	2 Hole
	B14-4-600I		60	2 Hole

2.6. Preparation of Test Specimens

Prior to casting the beams, the reinforcement cages were assembled according to the required details; Prior to mixing the concrete mix, the gravel was wetted and allowed to dry for 2 hours, after which the coarse and fine aggregates were added to the mixer and mixed for 2 minutes. The cement, silica fume and nano silica were added to the mix and mixed for another 2 minutes, and the water content was added by dissolving half of the super plasticizer in half of the water and adding half of the water to the mix for 1 minute. Then the other half of the super plasticizer was added to the mix for 1 minute, or until the concrete mixture has reached the desired consistency, then the concrete mix was casted in a wooden formwork. To obtain the properties of hardened concrete, the samples were left for 24 hours before being covered with soaked canvas and cured for 28 days.

2.6.1. Epoxy Injection

The grooves, where the Kemapoxy 103 was injected, were cleaned from any hardened concrete residue by using water pressure to ensure the total injection of the whole groove along the beam span. The beams were tested under four-point load test to achieve half of ultimate load achieved by the corresponding reference beam, then the grooves were injected with Kemapoxy 103 and was left to harden for 24 hours. After 24 hours of injecting the Epoxy, the beams were tested until the ultimate failure load was achieved as shown in figure 3.

Fig -3: Test Sample during and after Injection

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1. Fresh Concrete Properties

3.1.1. Slump Test Results

Slump test is used to measure the workability of the fresh concrete. Table 4 shows the results obtained from the slump test conducted on fresh concrete.

Table -4: Slump Test Results

Concrete Mix	%Nano Silica	Slump (mm)
300-0%	0	50
300-2%	2	40
300-4%	4	30
300-6%	6	28
450-0%	0	70
450-4%	4	40
600-0%	0	60
600-4%	4	50

3.2 Mechanical Properties of Concrete

3.2.1. Compression Test

The compression test was conducted on 15×15×15 cm, for each concrete mix three cubes were cast to obtain the average value of the compression strength. Table 5 shows the results of the compression test after 7 and 28 days.

Table -5: Concrete Compressive Strength after 7 and 28 days

Concrete Mix	Compressive Strength (MPa)	
	7 Days	28 Days
300-0%	22.17	31.31
300-2%	24.22	33.21
300-4%	25.04	36.83
300-6%	23.23	32.14
450-0%	32.60	46.24
450-4%	35.28	49.62
600-0%	43.05	61.41
600-4%	47.13	66.43

3.2.2. Splitting Tensile Test

Table 6 shows the test results of concrete splitting tensile strength after 28 days. It can be found that using 4% nano silica showed the best results in tensile strength with increase up to 42.6% compared to 0% nano silica.

Table -6: Concrete splitting Tensile Strength after 7 and 28 days

Concrete Mix	Tensile Strength (MPa)
	28 Days
300-0%	3.52
300-2%	4.34
300-4%	5.02
300-6%	4.41
450-0%	6.27
450-4%	6.55
600-0%	6.79
600-4%	7.81

3.2.3. Modulus of Elasticity

The Stress-strain curves of the tested cylinders are shown in figure 4 and the results are tabulated in table 7. From the results, it can be inferred that the use of 4% nano-silica provided the best results in terms of compressive strength.

Table -7: Concrete Modulus of Elasticity

Concrete Mix	F'c (MPa)	Modulus of Elasticity (MPa)
300-0%	26.51	10105.75
300-2%	28.08	10541.2
300-4%	31.57	12365.75
300-6%	27.23	13361.6
450-0%	39.13	9622.547
450-4%	42.54	13437.68
600-0%	51.8	10117.87
600-4%	55.84	13816.88

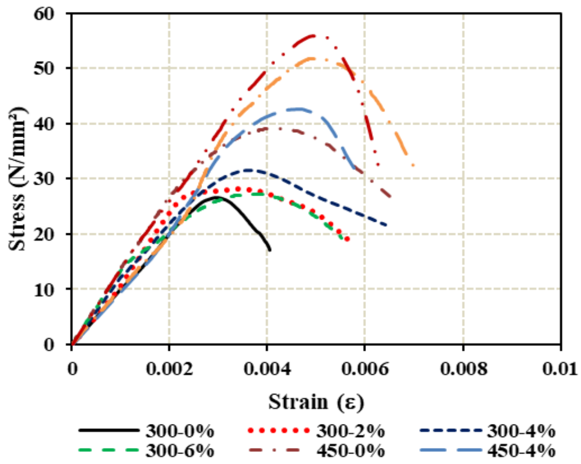


Fig -4: Concrete stress-strain curve

3.3. Results of the Tested Beams

Table 8 shows the results of beams as follows:

- The ultimate load (P_u)
- First crack load (P_{cr})
- Ultimate shear force (V_u) calculated from Eq. (1).
- Ultimate shear stress (τ) calculated from Eq. (2) according to the Egyptian Code of Concrete ECP 203-2017.[12]
- Crack moment (M_{cr}) calculated from Eq. (3).
- Ultimate moment (M_u) calculated from Eq. (4).
- Ultimate flexural stress (F_{ru}) calculated from Eq. (5).

$V_u = P_u/2$ .... Eq. (1)
$M_u = (P_u \times l)/6$ .... Eq. (2)
$M_{cr} = (P_{cr} \times l)/6$ .... Eq. (3)
$\tau = P_u / (b.d)$ .... Eq. (4)
$F_{ru} = (M_u \times y)/I_g$ .... Eq. (5)

Where $Ig = (b \times h^3) / 12$

Table -8: Test Results of the Tested Beams

Group no.	Beam ID	P_{cr} (KN)	P_u (KN)	V_u (KN)	τ (MPa)	M_{cr} (KN.m)	M_u (KN.m)	F_{ru} (MPa)
G1	B1-0-300	65.67	121.60	60.80	9.73	8.21	15.200	40.53
	B2-0-450	83.95	135.41	67.71	10.83	10.49	16.926	45.14
	B3-0-600	88.04	157.21	78.61	12.58	11.00	19.651	52.40
G2	B4-2-300	66.95	119.12	59.56	9.53	8.37	14.890	39.71
	B5-4-300	78.94	128.36	64.18	10.27	9.87	16.045	42.79
	B6-6-300	77.74	109.33	54.67	8.75	9.72	13.667	36.44
G3	B7-4-450	84.55	153.16	76.58	12.25	10.57	19.146	51.05
	B8-4-600	112.56	170.29	85.15	13.62	14.07	21.286	56.76
G4	B9-0-300I	73.77	122.96	61.48	9.84	9.22	15.370	40.99
	B10-0-450I	79.12	145.43	72.72	11.63	9.89	18.179	48.48
	B11-0-600I	111.46	164.63	82.32	13.17	13.93	20.579	54.88
G5	B12-4-300I	67.71	130.20	65.10	10.42	8.46	16.275	43.40
	B13-4-450I	105.02	154.44	77.22	12.36	13.13	19.305	51.48
	B14-4-600I	116.58	174.00	87.00	13.92	14.57	21.750	58.00

3.3.1. Crack Patterns of Beams

Table 9 and figure 5 are shown the ultimate deflection and absorbed energy (AE) of tested beams and failure mode.

Table -9: Ultimate Deflection and Absorbed Energy of Tested Beams and Failure Mode

Beam ID	Δ_u (mm)	AE (KN.mm)	% Increase in P_u	% Increase in AE	Failure Mode
B1-0-300	4.115	207.102			Shear
B2-0-450	2.812	213.964			Shear
B3-0-600	4.724	371.738			Shear
B4-2-300	5.16	297.192	25.39%	43.50%	Shear
B5-4-300	5.685	355.531	38.15%	71.67%	Shear
B6-6-300	5.877	290.553	42.82%	40.29%	Shear
B7-4-450	5.897	369.39	109.71%	72.64%	Shear
B8-4-600	6.114	610.296	29.42%	64.17%	Shear
B9-0-300I	4.186	257.459	1.11%	24.32%	Shear
B10-0-450I	4.212	296.537	7.40%	38.59%	Shear
B11-0-600I	4.524	411.318	4.72%	10.65%	Shear
B12-4-300I	6.094	399.026	1.44%	12.23%	Shear/ Flexural
B13-4-450I	6.288	415.513	0.84%	12.49%	Flexural
B14-4-600I	6.785	435.207	2.18%	0.00%	Shear/ Flexural

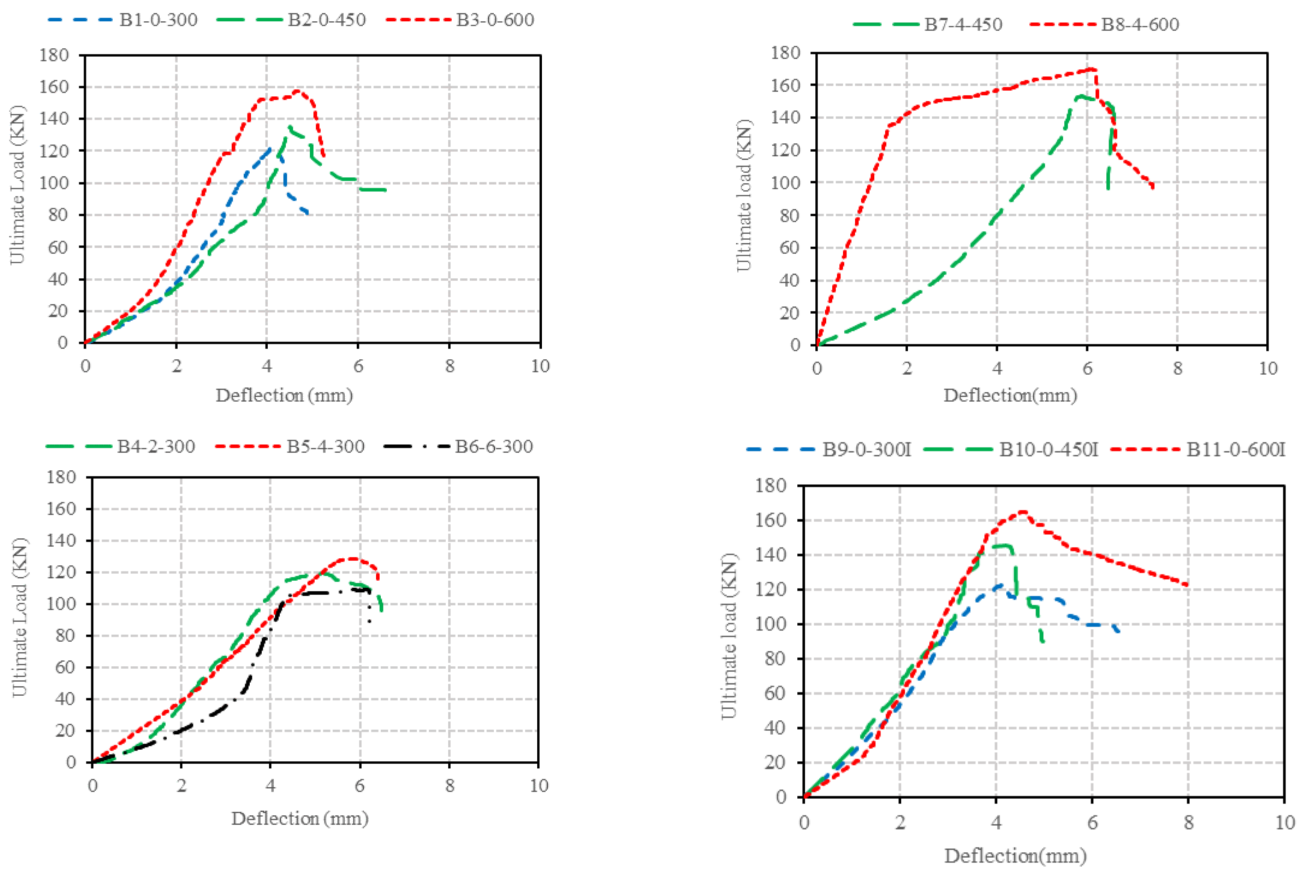
3.3.2. Load-deflection of Beams

All the beams were tested by four-point load test, from the figures for all groups it is noted that the behavior of the curve initiated linearly and changed to nonlinear behavior when the cracks took place.

Group 1 does not contain nano silica (control) and compressive strength (300,450 and 600 kg/cm2). Note that the higher the strength, the higher the ductility, and the 600 kg/cm2 strength, the better the results. The percentages of Nano silica in Group 2 were (2%, 4%, and 6%) (Control) and compressive strength (300 kg/cm2). Note that the higher the strength, the higher the ductility, and the 600 kg/cm2 strength, the better the results. Note that with the stability of the strength, and the increase of the nano silica, it was found that at 4%, the ductility increased. The percentages of Nano silica in Group 3 were 4% (control) and compressive strength (450, and 600 kg/cm2). It was discovered that as the nanosilica ratio stabilised and the strength increased, the ductility increased. Group 4 does not contain nano silica and compressive strength (300,450 and 600 kg/cm2) and all beams are reinforced with internal epoxy injection. The higher the strength, the greater the ductility, and the higher the strength (600 kg/cm2), the better the outcomes.

The percentages of Nano silica in Group 5 were 4% and compressive strength (300,450 and 600 kg/cm2) and all beams are reinforced with internal epoxy injection. Note that with the stability of the nano silica ratio, and the increase in the strength, it was found that when the strength 600 kg/cm2 increases, the ductility increases. It should be noted that with the stability of the nano silica ratio and the increase in strength, it was discovered that the ductility increased as the strength 600 kg/cm2 increased as shown in figure 6.

Fig -5: Cracking of the tested beams



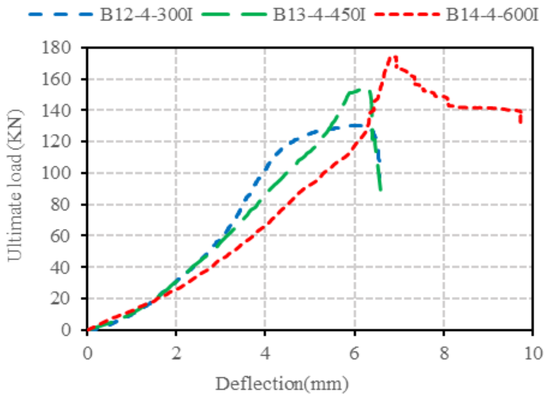


Fig -6: Load-Deflection Curves for Groups (1-5)

3.3.3. Ultimate load of beams

The ultimate loads of Group 1 It are clear from the results that ultimate load increases as compressive strength increases. Group 2 it can be seen from the results that both the ultimate load and the first crack load significantly increased using 4% nano-silica compared to 2% and 6%. Group 3 The results show that as compressive strength increase, ultimate load increase as well. Group 4 The results show that when compressive strength increases, ultimate load increases, where the rate of increase was 1.11%, 7.40% and 4.72% in B9, B10 and B11, respectively. Group 5 It is clear from the results that ultimate load increases as compressive strength increases, Where the rate of increase was 1.44%, 0.84% and 2.18% in B12, B13 and B14, respectively, as shown in figure 7.

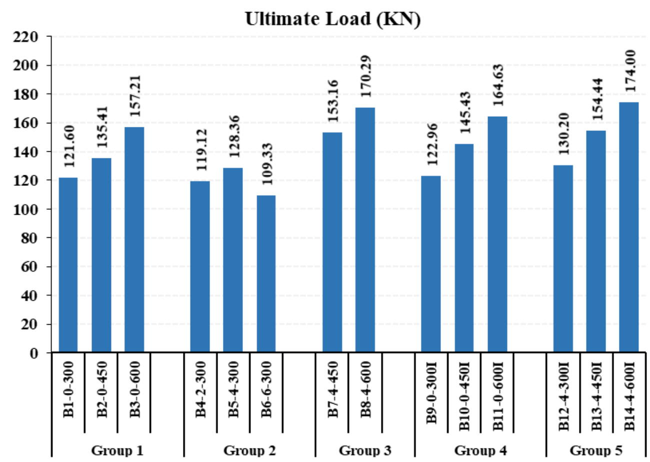


Fig -7: Ultimate Load for Groups (1-5)

3.3.4. First crack load of Beams

The first crack loads of Group 1 It is clear from the results that first crack load increases as compressive strength increases. Group 2 it can be seen from the results that first crack load significantly increased using 4% nano-silica compared to 2% and 6%. Group 3 The results show that as compressive strength increase, first crack load increase as well. Group 4 The results show that when compressive strength increases, first crack load increases, where the rate of increase was 12.35%, 17.80% and 26.60% in B9, B10 and B11, respectively. Group 5 It is clear from the results that first crack load increases as compressive strength increases, Where the rate of increase was 0%, 24.22% and 3.57% in B12, B13 and B14, respectively, as shown in figure 8.

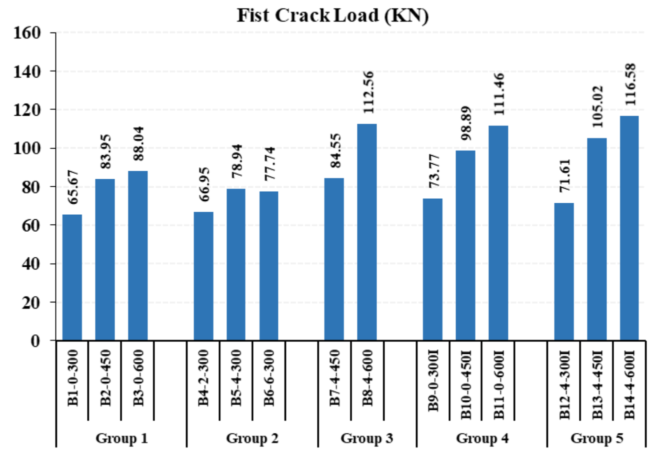


Fig -8: First Crack Load for Groups (1-5)

3.3.5. Ultimate Shear and Flexural Stress of Beams

The ultimate Shear and Flexural Stress of the control beams and the ultimate Shear and Flexural Stress of Groups 1-5 are shown in figures 9 and 10. The percentage of increase in them is the same as the increase that occurred in ultimate load compared to the corresponding control beam.

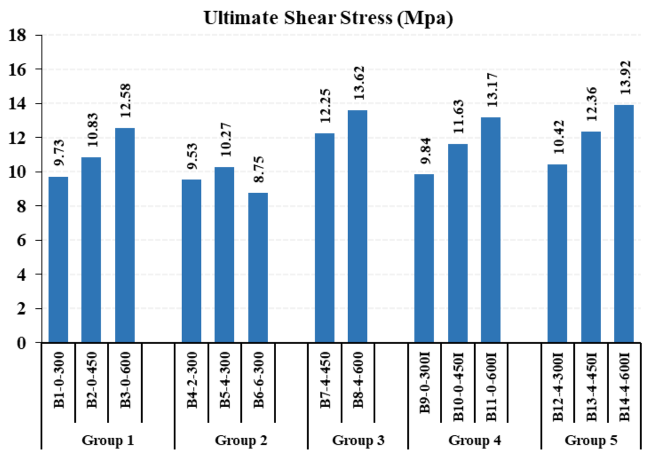


Fig -9: Ultimate Shear Stress for Groups (1-5)

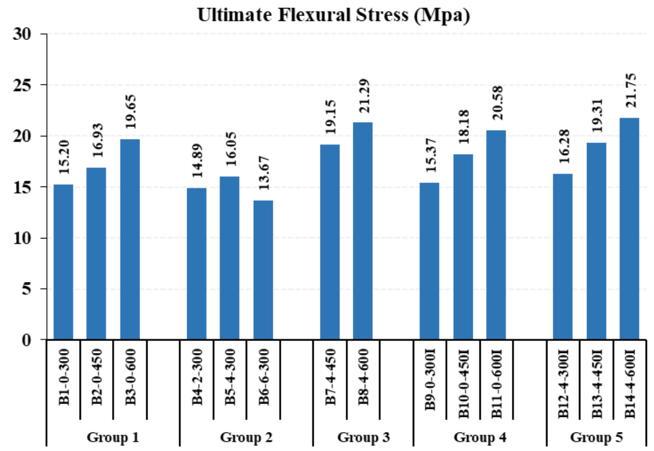


Fig -10: Ultimate Flexural Stress for Groups (1-5)

3.3.6. Ductility of Beams

The ductility of the control beams of Groups 1-3 and the ductility of Groups 4-5 are shown in figure 11. Where the rate of increase in-Group 4 was 24.32%, 38.59%, and 10.65% in B9, B10 and B11, respectively. Group 5 was 12.23%, 12.49%, and 0% in B12, B13and B14, respectively.

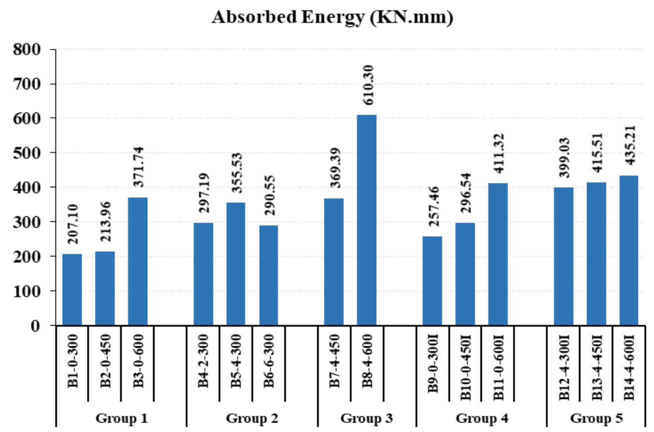


Fig -11: Absorbed Energy for Groups (1-5)

4. CONCLUSIONS

The objective of this experiment is to reach the best nano-silica ratio in increasing the strength and to examine the effect of using epoxy injection to strengthen the shear of RC beams. The main conclusion remarks are as the following:

1- For Beam, with no nano silica, the increase in the compressive strength resulted significant increase in both ultimate load and absorbed energy (ductility).

2- Beams with 4% nano silica, showed the best results in terms of ultimate load and ductility. Which agrees with the results concluded by Al Ghabban et.el.[5]

3- The use of injected kemapoxy103 increased the ultimate load and absorbed energy significant in most cases.

4- The use of injected kemapoxy103 increased the ultimate load by (0.84-7.4) % and increased the absorbed energy up to 38.6% compared to the control beams.

5- The increase in concrete compressive strength did not results in any increase in absorbed energy on the other hand the ultimate load increased significantly.

6- The increase in shear capacity was not signific, which could be due to the increase in the amount stirrups in the tested beams, and that is coincident with the research conducted by Mofidi and Chaallal.[13]

From the experimental results, it was found that pre-loading and injection of Kemapoxy 103 provides a better behavior.

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