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Behavior of reinforced concrete inverted T-section beams containing Nano-silica

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Abstract:- *Concrete has been developed in several ways to avoid environmental contamination and improve the quality and properties of concrete by replacing some cement with products from other industrial processes such as pozzolanic materials, including nano-silica (NS). The aim was to improve the concrete properties by filling the spaces between the cement particles, resulting in more dense and stronger concrete by using an ultrasonic device to prevent the nano-silica particles from agglomeration and to ensure their dispersion when the mixture was moistened with water. The effect of partial replacement of cement by nano-silica (NS) was studied by making several concrete mixtures with multiple ratios of nano-silica (NS), the ideal ratio was when using 1% nano-silica (NS) which increased the compressive strength of concrete by 8.5%, then. The behavior of 7 inverted concrete T-beams was studied and they were divided into three groups. In terms of nano-silica impact and change of reinforcement ratio (flexure and shear) in beams and results were increased concrete properties such as Ultimate load, Initial crack load, and toughness of inverted T- beams contain 1% NS as partial replacement of cement by 6.6%, 31.4%, and 16.65% respectively compared to control beam without NS.*
Keywords: *-pozzolanic materials, Nano-Silica (NS), Cement Replacement, inverted T-beams,Strength, Toughness, ultrasonic device*

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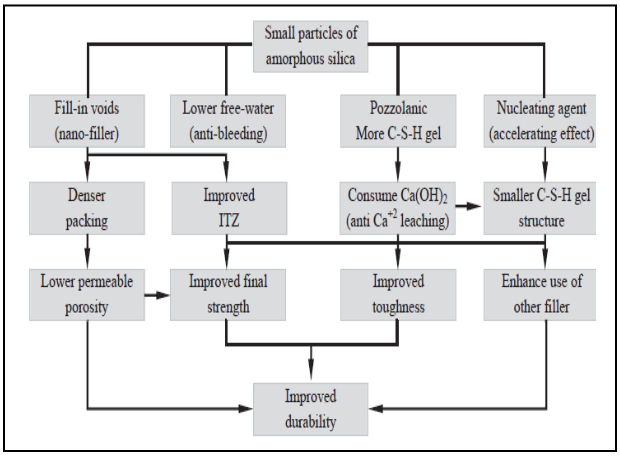
I. Introduction

Concrete is used extensively throughout the world because of the ease of availability of its components, preparation, and manufacture where cement is the main component of concrete. Its production needs very high energy, which leads to the production of co2 in large proportions, which leads to damage to the environment. Therefore, concrete must be developed to minimize damage to the environment, and to keep pace with the progress in construction and to ensure the future competitiveness of concrete as building materials[1-2]. Various researchers estimate that the cause of co2 emissions about 4.5 to 8% per year is the production of cement worldwide. Therefore, the reduction of cement clinker content may have a positive impact on the environmental aspects and several different methods have already been identified to reduce the environmental impact in the field of concrete construction, especially in concrete technology and raw material production [3]. However, it is important to ensure that the reduction of cement in the concrete does not negatively affect them, but the goal is to preserve the environment and development of concrete materials to be more efficient as these changes can help to make the concrete the same performance or better but with low cement consumption[4].In the past few years, many researches have been indicating to nanotechnology can be applied to cement. Researchers have found that the addition of 1 kilogram of micro-silica allows a reduction of approximately 4 kg of cement, and If nano-silica (NS) is used this number might be higher. It also produces a better quality of cement particles due to the incorporation of different types of nanomaterials such as nano-silica (SiO2). Where the nanomaterials are used to improve the mechanical properties of cement materials such as compression strength, tensile strength, corrosion resistance, and cracks. The addition of nano-silica in cement can lead to different effects as in figure(1).[3-4]. However, there is a major problem when using nano-silica, although it adds to the strength and durability of concrete, But its particle is very agglomerated after wetting the powder, which leads to loss in the high surface area, so there is a need for effective means to remove the agglomeration and dispersion after moistening the powder to break the bonding force between its molecules[5]. Sonication is the best method used to prevent the agglomeration of nanoparticles and improved the dispersion of nanoparticles when moisturizing with water. this research showed that the best Sonication time for 5 minutes at concentrations of nano-silica of 1: 10 and that the compression strength increased by 25% after 28 days compared with control mix, On the other research, the compressive strength of cement paste increased by 27% compared to the control mix when using sonication that 9 minutes [6].Numerous research has been done on the use of nano-silica in structural elements there is a significant improvement in the mechanical properties of structural elements containing nano-silica. Compared to ordinary concrete, the compressive strength of nano-silica concrete is higher than ordinary concrete.The use of nano-silica and nanomaterials in small quantities in reinforced concrete can improve the strength of compression, flexure, and tensile strength and reduce the permeability of concrete. Because nano-silica fills the voids in concrete, it makes them stronger and denser, and Nano-silica coated concrete has a very low of the permeability so nano-silica can be used as an external coating that leads to a solid concrete construction[7-8-9-10]



Figure(1): Schematic diagram of the effects of nano-silica addition in concrete.

II. Research Objective

The objectives of this study can be summarized as follows:

1- Identification the optimum ratio of nano silica, which increases the strength of concrete.

2-Study the behavior of structural member like inverted T- beams with concretes incorporating nano particles.

3-Study the effect of addition of Nano-SiO2, shear reinforcement ratio and flexure reinforcement ratio for concrete inverted T-section beams

III. Test Materials

The materials used in this study were selected and tested according to the Egyptian specifications as follows:

- **The cement**(CEM I, 42.5N) used in this research is produced by El Sewedy Cement Factory whose chemical and physical properties satisfy the requirements of the Egyptian standard Specifications (E.S.S. 4756-1/2009) **[**11**].**
- **The fine aggregate** used in this research is natural sand and middle size . Its characteristics satisfy the requirements of the Egyptian Code of Practice (E.S.S. 1109/2008) [12]. Its properties are shown in table(1). Its grading is shown in table(2).
- **The Coarse aggregate** used in this research is Crushed dolomite , Its Properties satisfy the requirements of the Egyptian Code of Practice (E.S.S. 1109/2008) [12]. Physical and Mechanical Properties of Dolomite are shown in table (3). Its grading is shown in table (4).
- The tap water used to mix and treat the samples was clean, drinkable, and free from impurities affecting the hardening of the concrete**.**
- Nano-Silica is a new pozzolanic substance that studies have proven to be the best pozzolanic material which improves various properties such as durability, strength, etc. It fills in the spaces between the cement particles and thus produces more strong concrete. In this experimental test, the cement was replaced by different ratios (0.5%, 1%, 1.5%, 2%, 3%, and 4%) nano-silica by weight to make the first stage of this test and reach the optimal ratio which gives me the largest Value for strength of concrete. Then use the ideal nano-silica ratio in the second stage, which is the work of concrete beams and study their behavior and mechanical properties. To make concrete inverted T-section beams and study their behavior and mechanical properties. The properties of nano-silica are shown in table (5), and figure (2).
- **Reinforced steel** used is high tensile steel of (10 and 12 mm) diameter with a yield strength of 360 N/mm2 and the ultimate strength of 520 N/mm2 has been used as the main reinforcement steel of the tested beams.

Mild steel of 8mm diameter with yield strength of 240 N/mm2 and ultimate strength of 350 N/mm2 had been used as internal shear reinforcement (stirrups).

Then,the concrete mixture is designed in an absolute volume method to get grades of concrete resistance 30N/mm2. The compression test is conducted on the cubes specimens after 28 days. The different components of one cubic meter of concrete are shown in table(6).

Table (1): Physical and Mechanical Properties of Sand.

Property	Value
Specific gravity	2.6
Volume weight(t/m3)	1.73
% Absorption	0.78
Void ratio	33.80%
Fineness modulus	2.72

Table (3): Physical and Mechanical Properties of Dolomite.

Property	Value
Specific gravity	2.71
Volume weight (t/m3)	1.84
Absorption ratio (%)	0.65%
Void ratio	32%
Fineness modulus	6.48

Table (2): Grading of used Sand

Sieve size (mm)	4.76	2.36	1.18	0.61	0.31	0.16
% Passing(ASTM C33)	100-95	100-80	85-50	60-25	30 -10	10-2
% Passing used sand	100	96	77	50	16	3

Table (4): Grading of used Dolomite

Sieve size (mm)	19	12.7	9.52	4.76	2.36
%Passing (ASTM C33)	100	100-90	70-40	15- 0	5 - 0
% Passing used dolomite	100	99.7	58.4	3.1	0.9

Table (5): Properties of nano-silica

Property	Nature or Value
Color	White
Form	Amorphous
Bulk density	0.2 g/cm3
Particle size/nm	≤100
Molar mass(g/mol)	60.08

Figure (2): Nano-Silica

Table (6): Concrete mixing proportions, kg/m3.

Mixture	Fine aggregate (kg/m3)	Coarse aggregate (kg/m3)	Nano-silica (kg/m3)	Cement content (kg/m3)	w/c ratio	Water (Lit)	Grade of concrete
NM	694	1289	0	350	0.45	158	M30
M with 1 % NS			3.5	346.5			

Mix Ratio = 1:1.98:3.6 Normal mixtures (NM), Mixture (M) and Nano-Slica (NS).

IV. Test Specimens

The experimental study involves two phases:

- **The first stage** is to manufacture 21 cubes with different ratios of nano-silica (0.5%,1%,1.5%,2%,3%and4%) to obtain the ideal ratio of nano-silica for use it in the second stage and because nano-silica tends to agglomerate when moistening the mixture with water must be used **Ultrasonic** device where it works to prevent agglomeration and improve the dispersion between the molecules[13]. The device was used and put a third of the amount of water used for the mixture with nano-silica for a quarter of an hour and then put them in the mixer with the rest of the components and water and the work of cubes and treatment and then tested after 28 days as in figure(3),(4).

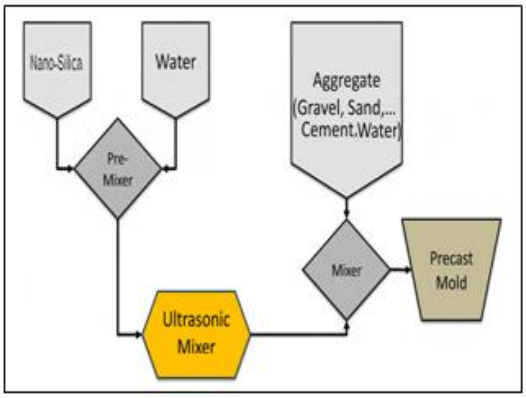


Figure (3): Ultrlasonic device**Figure (4):** Mixing steps

- **The second stage**is manufacturing 7 reinforced concrete inverted T-section beams with the same dimensions (depth of 200 mm, a flange thickness of 100 mm, a flange width of 300 mm, a web width of 100 mm and length 2000 mm). Figure (5) and table (7) show the details of the reinforcement of beams. The deflection in beams was measured by dial gauge as in fig.(6)

The casted beams were divided into three groups:

Group 1: The first group consists of two beams (B1andB2). One of them is the control beam(B1) without nano-silica, and the other contains 1% nano-silica. To study the effect of partial replacement of nano-silica cement on beams.

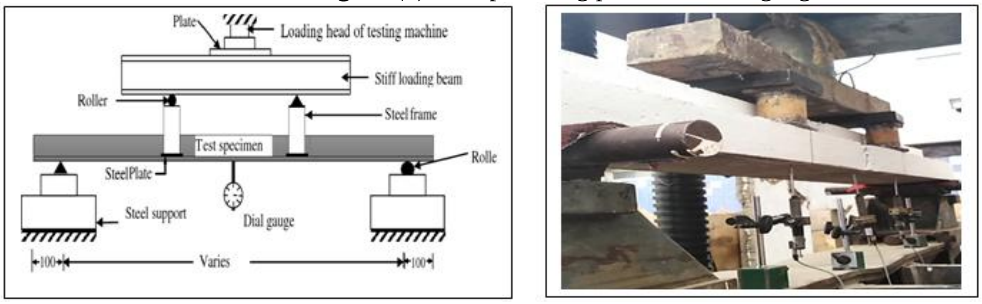
Group 2: The second group consists of three beams(B3, B4, and B5), contains (1%) nano-silica, with different longitudinal reinforcement in the bottom of the web for the 3 beams.They were designed to observe the flexure failure.

Group 3: The third group consists of two beams (B6 and B7), contains (1%) nano-silica, with different transverse reinforcement (closed stirrups) for 2 beams.They were designed to observe the shear failure.

Table (7): the details of reinforcement of beams:

Group	Beam No.	%NS	Fcu(mpa)	Reinforcement			
				flange	web		Stirrups
					Upper	Lower	
A	B1	Control (0%)	30	4Ø10	2Ø10	2Ø12	5Ø8/m`
	B2	Control (1%)	30	4Ø10	2Ø10	2Ø12	5Ø8/m`
	B3			4Ø10	2Ø10	4Ø12	5Ø8/m`

Figure (6): Setup loading points and dial gaug



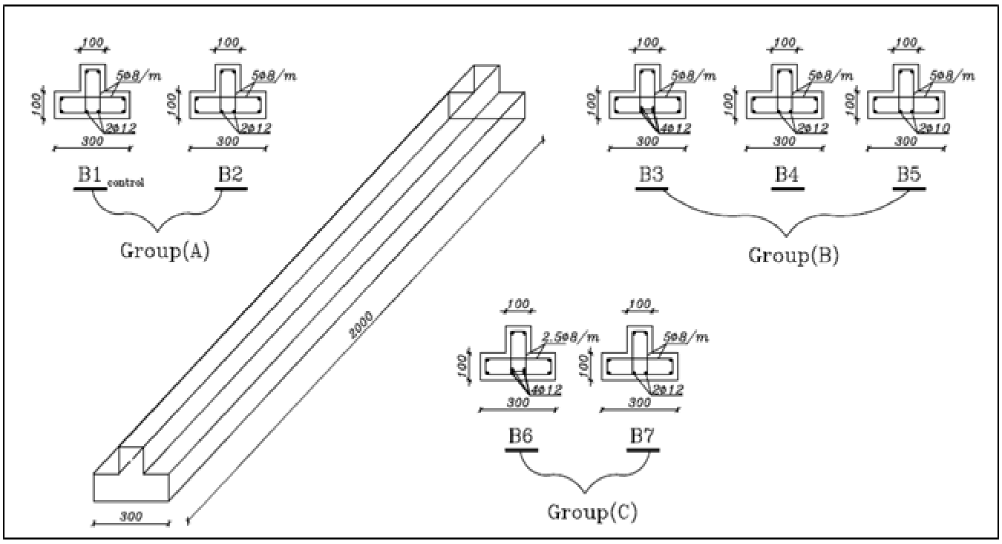


Figure (5) : The details of reinforcement of beams**.**

V. Results

concrete cubes were tested which contained different percentages of nano-silica(NS) and the result was that 1% of nano-silica(NS) was the ideal ratio, increasing the compressive strength of the concrete by 8.5% as shown in figure(7).

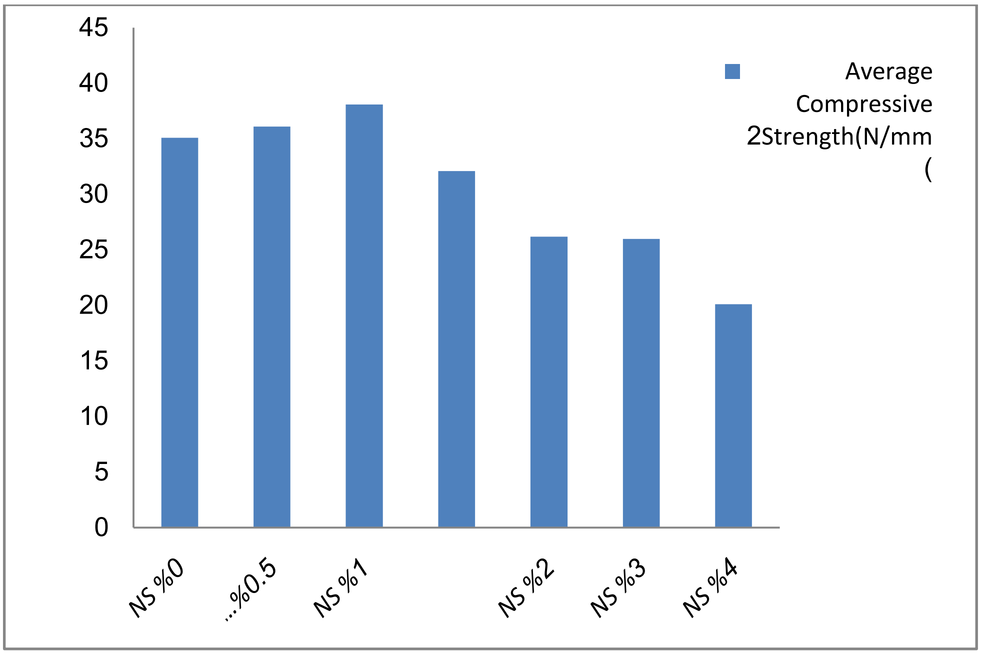


Figure (7): Results of average Compressive Strength of the Cubes

Then, the second stage of the research was carried out using 1% nano-silica (NS) obtained in the previous stage where The inverted T-beams were tested under four points until failure. Failure modes, crack patterns and deflection were studied for all T-beams. Table (9) show the ultimate load (Pu), initial crack load (Pc) and failure type. The corresponding deflection was measured from the bottom of the middle of the beam(δu,δm).

Table(9): Experimental results of the tested beams

Group	**Beam no.**	**Actual fcu (Mpa)**	**Intial crack load: Pc (KN)**	**Ultimate load: Pu (KN)**	**Ultimate deflection: δu (mm)**	**Max. deflection: δm(mm)**	**Toughness (KN.mm)**	**Type of failure**
A	**B1**	37.2	35	76.55	17.793	31.843	2557.471	Flexure
	B2	40.3	46	81.57	9.63	34.96	2983.312	Flexure-shear
B	**B3**		51	99.14	22.759	32.559	3248.411	Flexure-shear
	B4		45	80.32	9.627	34.86	2952.991	Flexure-shear
	B5		43	66.51	12.052	29.848	2135.27	Flexure-shear
C	**B6**		38	89.1	11.724	35.142	3131.152	Shear
	B7		50	99.14	23.765	32.087	3181.105	Flexure-shear

5.1 crack patterns for inverted T-beams:

Fig (8) to fig (14) show the crack patterns and the failure modes occurred for tested inverted T-beams . It is observed that all beams fails in Flexure-shear mode except for the control B1failed to flexure and B2 failed to shear.

Figure (8): Crack pattern for control beam (B1)

Figure (9): Crack pattern for control beam (B2)

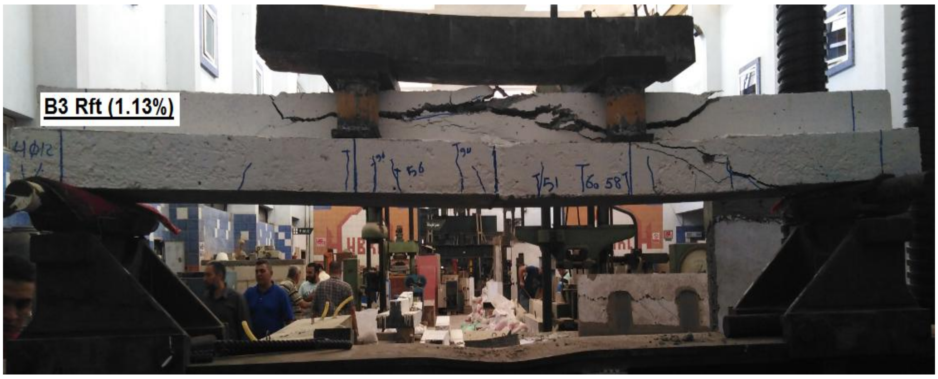


Figure (10): Crack pattern for control beam (B3)

Figure (11): Crack pattern for control beam (B4)

Figure (12): Crack pattern for control beam (B5)

Figure (13): Crack pattern for control beam (B6)

Figure (14): Crack pattern for control beam (B7)

5.2Load–deflection curves

Inverted T-beams were tested and measure the load(KN) and the corresponding deflection (mm), then a curve was drawn Load (KN) and deflection (mm) as shown in figures (15) to (17).

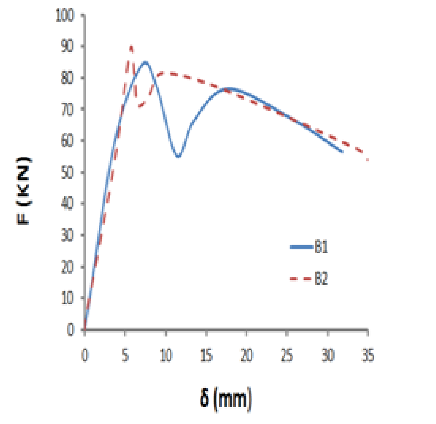


Figure (15): Load(f) - displacement(δ) relation for beams(B1&B2)

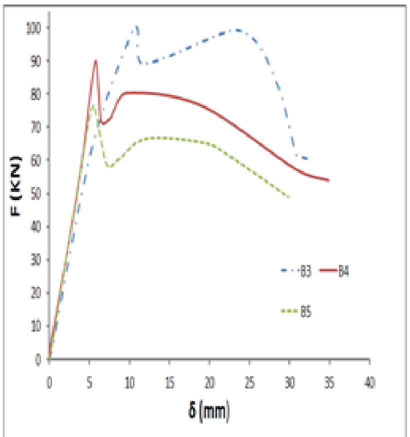


Figure (16): Load(f)-displacement(δ) relation for beams(B3&B4&B5)

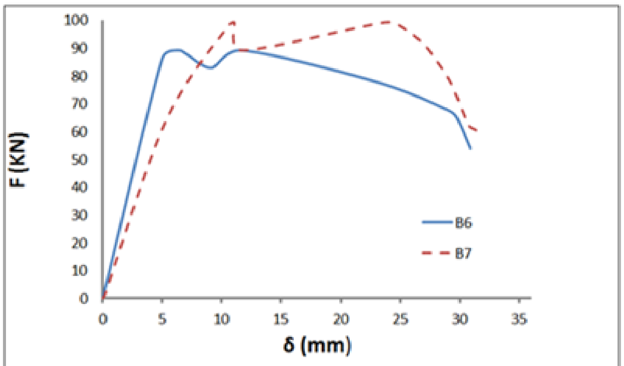


Figure (17): Load (f) - displacement(δ) relation for beams(B6&B7)

VI. Discussion

- **effect of adding nano-silica ratio**

Includes two beams with the same dimensions and reinforcement, Beam (B1) was control beam without nano-silica but B2 was contained 1% nano-silica, and The results showed that B2 with 1% nano-silica had a higher carrying capacity than control beam (B1), where the ultimate load increased by(6.6%), and the cracking load increased by (31.4%).In addition, the toughness increased by (16.65%) compared to the beam B1) as shown in figure (18). The results show that we can improve the performance and properties of concrete by partial replacement of cement by 1% of nano-silica instead of elevating concrete grade.

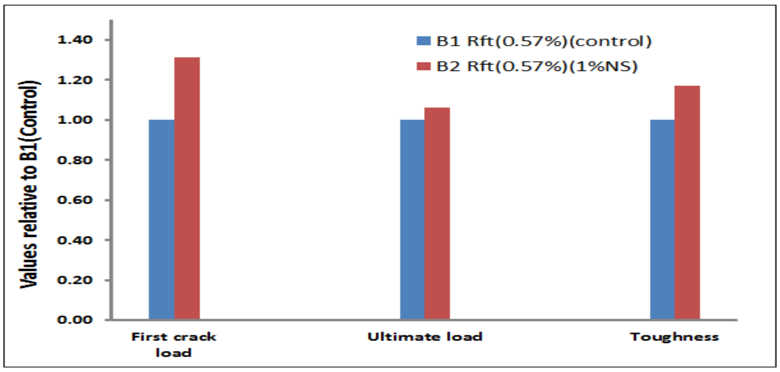


Figure (18): Effect of ultimate load , cracking load and toughness for B2with B1

- **flexure reinforcement ratio:**

The ultimate load, cracking load and toughness increased by 23.4%,13.3%, and 10% respectively for RFT(1.13%) when the reinforcement was doubled (steel in Lower of the web)compared to RFT (0.57%) , but when reduced reinforcement to RFT (0.39%) the ultimate load, cracking load and toughness decrease by 17.2%, 4.4%, and 27.6% respectively when compared with RFT(0.57%) as shown in figure (19). The result shows that RFT(1.13%) has the highest carrying capacity as a result of doubled reinforcement.

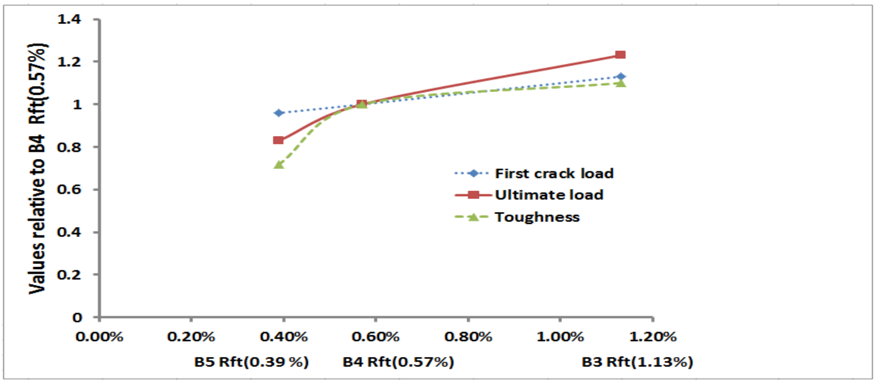


Figure (19): Effect of ultimate load , cracking load and toughnessfor B4 with B3 and B5

- **shear reinforcement ratio:**

reduced ofreinforcement from RFT (0.07%) to RFT (0.035%). The ultimate load, cracking load and toughness was decreased by 10.1%, 24%, and 13.45% respectively as in figure(20). The result shows that RFT(0.07%) has the highest carrying capacity as a result of doubled shear reinforcement.

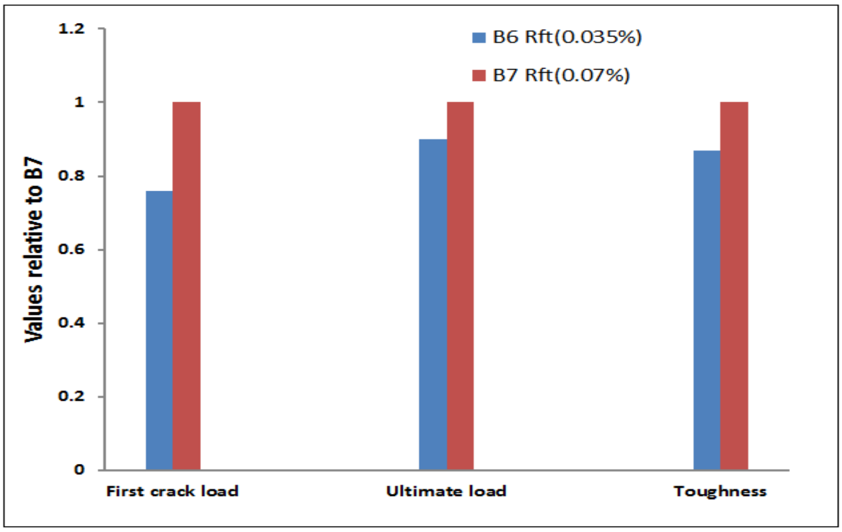


Figure (20): Effect of ultimate load , cracking load and toughnessfor B7 with B6

VII. Conclusions

In this research different ratios of nano-silica were studied to determine their effect on the mechanical properties of concrete and to obtain the ideal ratio that produces more effective concrete and then study the behavior of reinforced concrete inverted T-section beams containing Nano-silica and without it. also, study the effect of Change the shear reinforcement for some beams and others change the flexure reinforcement, seven beams were cast in the same dimensions and tested, The results are summarized as follows:

1. The ideal ratio of nano-silica (NS) was 1% which increased the compressive strength of concrete by 8.5%
2. Ultimate load, Initial crack load, and toughness of inverted T- beam (B2) with 1% NS as partial replacement of cement increased by 6.6%, 31.4%, and 16.65% respectively compared to B1 control beam without NS.
3. Usage concrete with NS in the beam (B2) has change failure mode from flexure to the flexure-shear mode and cracking spacing is lesser in NS concrete compared to normal concrete(B1).
4. The efficiency of the beam was increased when the ratio of the reinforcement was doubled to RFT (1.13%). and Both ultimate load, Initial crack load, and toughness increased by 23.4%,13.3% and10% respectively compared to RFT (0.57%), While ultimate load, cracking load and toughness decrease by 17.2%, 4.4%, and 27.6% respectively for beam include RFT (0.39%).
5. Reduced of shear reinforcement from RFT (0.07%) to RFT (0.035%). leads to decrease ultimate load, cracking load and toughness by 10.1%, 24%, and 13.45% respectively
6. Based on the present research, the addition of Nano-silica improves the performance of concrete mixes; it increases the compression strength of concrete and the durability of the beam and reduced the cracking spacing.

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