Influence of Nano Silica on the compressive strength and flexural behaviour of Bridge rubberised concrete

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Abstract. Based on the need of light weight concrete used in the bridge construction to reduce loadings on foundation and in the same time maintain enough strength to resist the stresses developed from the structure. Incorporation of recycled rubber from scrap tires in concrete as a partial replacement of course aggregate in production of new type of recycled aggregate lightweight concrete has provided many beneficial effects to both concrete and environments. Many properties of tire rubber concrete are improved compared with normal concrete. However, disadvantage such as reduction in rubber concrete strengths have limited the application of rubber concrete drastically. Therefore, this study presents a new method on producing rubber concrete with comparable compressive strength to Normal concrete strength (without rubber aggregate) by adding Nano silica as a partial replacement of binder (cement). The experimental program includes Four mixes, with one ratio of rubber (10 %,) as a partial replacement of course aggregate by weigh and , one of them is the reference rubberized concrete mix (without NS) and the other three is with three different ratios of Nano silica (0.5%, 1% and 1.5%) from the weight of cement . The experimental program also includes 36 samples were prepared and tested as 6 cubes for compression strength test, three of them in age of 7 days and the other three in age 28 days, and 3 prisms for flexural strength test.The data that obtained from the experimental program indicates that the compression and flexural strength properties of the rubber concrete increases nonlinearly with the increase of Nano silica ratio .The comparison between reference rubber concrete samples (without Nano silica) and other rubber concrete samples (with Nano silica), showed that the compression strength of rubber concrete in age of 7 days increases about (15%, 28% and 43%) for Nano silica (NS) ratio of (0.5%, 1% and 1.5%) respectively The increase in flexural strength was less but still obvious which is about(9%, 15% and 26%) for Nano silica (NS) ratio of (0.5%, 1% and 1.5%) respectively as well. The ultimate strength results of rubberized concrete with NS that obtained from the experimental work was with highest ratio of NS 1.5%.

1. Introduction
The loadings come from of the superstructure and substructure of bridges are high on the bridge foundation which will lead to severe settlement and may be damage of structure; therefore, lightweight and high strength concrete is needed for bridge construction. The Currently, waste materials such as vehicles tires are the most important challenge in the industrial and developing countries. Further investigations on wastage recycling are being carried out to minimize the environmental damages. In this regard, construction researchers, like other recycling and production industries, have also
accomplished advances in using waste materials. One of the non-recyclable materials enters the environment is vehicles used tires. Investigations show that used tires are formed of materials, which do not dissolve under environmental conditions and cause remarkable pollution. Burning is an option for their decomposition; however, the gases comes from the tire burning results in serious pollutions itself. Based on experiment investigations, another way is using the tires in concrete industry. This results in the improvement of such dynamical and mechanical properties as ductility, energy adsorption, and resistance to cracking. At the same time, this may cause a decrease in compressive strength of the concrete, which may be improved by adding Nano materials to rubber- containing concretes.

Nano materials are very small sized materials with particle size in nanometres. These materials are very effective in changing the properties of concrete at the ultra-fine level by the virtue of their very small size. The small size of the particles also means a greater surface area. In recent years, modification of cement composites by nanoparticles has attracted intension on among researchers. Concrete as the most popular cement composition practical applications, was also subjected to modification by replacing a portion of binder with various nano particles such as TiO2 [1], Fe2O3 [2], Al2O3 [3], and SiO2. Among those, nano silica (NS) incorporation into concrete was of interest for many researchers not only because of the similarity of its chemical composition to constituents of C-S-H, but also because of the capability of NS to potentially improve cement. Composites properties through different mechanisms. NS, as well as silica fume [4], is a highly reactive pozzolan and could consume calcium hydroxide (CH) to form secondary C-S-H [5, 6]. However, some researchers [7] believe that the addition of NS mostly affects initial silicate polymerization rather than ultimate amount of C-S-H formed. Another mechanism, by which NS can influence cement composite properties, is seeding effect. NS could provide extra sites for the precipitation of hydration products, leading to the acceleration of early stage hydration [5]. The modification of macroscopic properties of concrete by NS addition has been subjected to intensive study. As far as compressive strength is concerned, controversial results were obtained sorting enhancements from notable [8, 9] to moderate [10–14], even though no gains were reported [15, 16].

The present study is composed of experimental tests aim to investigate the activity of Nano Silica on the compressive strength of rubberized concrete at age 7 days and age 28 days and also to investigate the effect of nano-silica on the flexural strength of rubberized concrete and finally hopes to present a recycled environmentally friend light weight concrete with almost the same strength and properties of conventional normal concrete. This new production may cost more than normal concrete and this is considered as a disadvantage of the new concrete.

2. Experimental Work

2.1. Testing Program and Specimens Details

In order to obtain the current paper aims, the program of the experimental work consists of casting and testing 36 specimens, divided into four groups, each group consists of six cubes with dimensions of (150*150*150) mm and three prisms of dimension (500*100*100) mm. The first group consists of rubberized concrete (without Nano silica) and the other three groups consists of rubberized concrete with three different ratios of Nano Silica (0.5%, 1% and 1.5%) as a partial replacement from the weight of cement. All four groups contains the same tire rubber aggregate (TRA) which is 10% as a partial replacement of course aggregate. Details of four Groups showed in Table (1).

| Group No. | Rubber Aggregate ratio (RAR)% | Nano Silica ratio NSR% |
|-----------|-------------------------------|-----------------------|
|           |                               |                       |
2.2 Material Properties
This section presents details of the constituent material properties required in the casting of cubes and prisms for this experimental work which are (cement, fine aggregate, coarse aggregate, tire rubber aggregate, Nano Silica and water).

2.2.1 Cement
Ordinary Portland cement (Type I) is used in this study. The cement is manufactured by Mass cement factory (Iraqi factory). It was stored in airtight plastic containers to avoid exposure to humidity. The physical analysis and chemical test results for the used cement are given in Tables (2) and (3) respectively. Test results indicate that the adopted cement conformed to the Iraqi specification No. 5/1984 [12]. The chemical and physical tests were made in the National Center for Construction Laboratories and Research (NCCLR).

| Physical properties | Test results | Iraqi specification No. 5/1984 |
|---------------------|--------------|--------------------------------|
| Fineness            | 354          | 230**                          |
| Soundness           | 0.04%        | 0.8%*                          |
| Setting time        |              |                                |
| Initial (min.)      | 132          | 45**                           |
| Final (hr.)         | 2.5          | 10*                            |
| Compressive strength for cube(70.7mm) at: | | |
| 3days(MPa)          | 24.5         | 5**                            |
| 7days(MPa)          | 34.0         | 23**                           |
Table 3. Chemical Composition of Cement

| No. | Compound composition | Chemical composition | Weight (%) | Iraqi specification No. 5/1984 |
|-----|----------------------|----------------------|------------|-------------------------------|
| 1   | Lime                 | CaO                  | 61.07      | -                             |
| 2   | Silica               | SiO2                 | 20.24      | -                             |
| 3   | Alumina              | Al2O3                | 5.41       | -                             |
| 4   | Iron oxide           | Fe2O3                | 3.48       | -                             |
| 5   | Magnesia             | MgO                  | 2.49       | 5*                            |
| 6   | Sulfate              | SO3                  | 2.1        | 2.8*                          |
| 7   | Loss on ignition     | L.O.I                | 1.43       | 4.0*                          |
| 8   | Insoluble residue    | I.R                  | 0.68       | 1.5*                          |
| 9   | Lime saturation factor | L.S.F           | 0.83       | 0.66-1.02                     |
| 10  | Tricalcium aluminates | C3A                | 8.78       | -                             |
| 11  | Tricalcium silicate  | C3S                  | 41.33      | -                             |
| 12  | Dicalcium silicate   | C2S                  | 29.1       | -                             |
| 13  | Tricalcium alumina ferrite | C4AF          | 9.12       | -                             |

2.2.2 Fine Aggregate (sand)

Natural sand from (Al-Ukhaidher) region in Iraq was used for concrete mixes. The fine aggregate has 4.75mm maximum size with rounded-shape particles and smooth texture with fineness modulus of 2.84. The grading of the fine aggregate is shown in Table (4). The obtained results indicate that the fine aggregate grading and the sulfate content are within the limits of Iraqi specification No. 45/1984 [13] and ASTM C33-03[14]. Table (5) shows the specific gravity, sulfate content and absorption of the fine aggregate.

Table 4. Grading of fine Aggregate

| No. | Sieve size | Passing (%) | Fine Aggregate | Iraqi specification No. 45/1984 | ASTM C33-03 |
|-----|------------|-------------|----------------|---------------------------------|-------------|
| 1   | 4.75 mm    | 90.56       | 90-100         | 95-100                          |             |
| 2   | 2.36 mm    | 80.50       | 75-100         | 80-100                          |             |
| 3   | 1.18 mm    | 60.44       | 55-90          | 50-85                           |             |
| 4   | 600 μm     | 43.47       | 35-59          | 25-60                           |             |
| 5   | 300 μm     | 13.72       | 8-30           | 5-30                            |             |
| 6   | 150 μm     | 1.98        | 0-10           | 0-10                            |             |
| 7   | Pan        | 0           | -              | -                               |             |
Table 5. Physical Properties of fine Aggregate

| Physical properties     | Test results | Iraqi specification No. 45/1984 |
|------------------------|--------------|---------------------------------|
| Specific gravity       | 2.66         | -                               |
| Sulfate content (so₃)  | 0.4 %        | ≤ 0.5 %                         |
| Absorption             | 1.75 %       | -                               |

2.2.3 Course Aggregate (gravel)
Crushed gravel from (AL-Nibaree) region with max. Size of 10mm is used. The coarse aggregate is washed, and then stored in a saturated dry surface condition before using. The specific gravity and absorption are 2.65 and 0.57% respectively. The grading of the coarse aggregate is shown in Table (6). The results indicate that, the coarse aggregate grading is within the requirements of Iraqi specification No. 45/1984 [14].

Table 6. Grading of coarse Aggregate

| No. | Sieve size | Passing (%) |
|-----|------------|-------------|
|     |            | Coarse Aggregate | Iraqi specification No. 45/1984 | ASTM C33-03 |
| 1   | 20 mm      | 100          | 100                          | 100         |
| 2   | 10 mm      | 83.34        | 50-85                        | 85-100      |
| 3   | 5 mm       | 5.5          | 0-10                         | 10-30       |
| 4   | 2.36 mm    | 0            | -                            | 0-10        |
| 5   | 1.18 mm    | 0            | -                            | 0-5         |
| 6   | pan        | 0            | -                            | -           |

2.2.4 Waste Tire (Rubber) Aggregate:
Disposable tires from light vehicles, such as cars and from heavy vehicles such as trucks were used. The tires were cut by both special machines and manually using cutters. They were cut into shreds of (10×10×10) mm as shown in Figure (1). In the study all the four mixes contained a rubber aggregate ratio (RAR) of (10%) were used as a partial replacement of coarse aggregate. The waste tire fibers were tested in the National Center for Construction Laboratories and Research (NCCLR) to obtain its physical properties. The physical properties of the rubber are shown in Table (7).
Table 7. Physical Properties of rubber shreds.

| Physical properties | Test results | Specification No. |
|---------------------|--------------|-------------------|
| Specific gravity    | 1.16         |                   |
| Density             | 1.16 g/cm³   | ASTM D1895-03     |
| Ultimate tensile    | 9 Mpa (N/mm²)| ASTM D412-02      |
| strength            | 150%         | ASTM D412-02      |
| Elongation at Break | 64           | ASTM D2240-05     |
| Absorption          | 1.12%        | ASTM D540         |

2.2.5 Nano Silica:
Strong hydrophobic nano silica with the average size was found to be 236 nm from Particle Size Analyser. It has been used as a partial replacement of cement because the nano-silica is amorphous in nature therefore, it will act as both filler and pozzolanic material. Figure (2) Shows the nano silica used in the study.

![Figure 2. The nano silica used in the study.](image)

2.2.6 Mixing Water
Tap water was used for casting and curing all the concrete samples.

2.3 Mix Proportions
Mix proportions were conducted by trail mixes according to the previous research, more than three mixes were made to achieve concrete strength targets of (18-20 MPa) which is the average value of rubberized concrete for rubber aggregate ratio reaches to 10% from the coarse aggregate all groups contained the same rubber aggregate ratio which is 10% as a partial replacement of course aggregate; group 1 consists of rubberized concrete without Nano Silica and groups 2, 3, 4 consist of rubberized concrete with different Nano Silica replacement ratios (0.5%, 1% and 1.5%); Mix proportion were 1:1.5:3  w/c=0.45 by weight. As shown in table (8):

Table 8. Mix proportions for Concrete

| Groups | Cement Kg/m³ | Sand Kg/m³ | Gravel Kg/m³ | rubber Kg/m³ | Water Liter/m³ |
|--------|--------------|------------|--------------|--------------|---------------|
| 1-4    | 378.8        | 568.2      | 1022.4       | 113.6        | 170.5         |

2.4 Mixing, Casting and Compaction Procedure:
The samples are casted and manufactured in four groups as mentioned earlier. A horizontal rotary mixer of 0.19 m³ capacity was used for mixing. Before using the mixer, any remained concrete from a previous batch is cleaned off.
Initially, fine and coarse aggregates (rubber and gravel) are washed to remove any clay particles and then, all quantities are weighed and poured into the mixer and mixed before adding the water, the rubber also added before adding water, then adding 50% of the water and mixed again, and then adding the remaining water with the super fine Nano silica dissolved in it gradually to the mixture, and the total time of mixing was (8-10 min).

Fresh concrete is placed in two equal layers; each layer is compacted by 25 beat by a solid uniform steel bar, after the top layer has been compacted, it is smoothened and levelled with the top of the formwork by using a steel trowel.

2.5 Curing:
After finishing the procedures of casting, compacting and finishing the surface of the specimens, the specimens have been covered by nylon to prevent evaporation of water from fresh concrete. After 24-48 hours; the specimens were stripped off from the formwork and completely immersed in potable water some for a period of 7 days and others for 28 days as will explained in tests. After the end of curing period, the specimens are removed from the water, and kept for two days in the air for drying.

2.6 Testing:

2.6.1 Testing Machine:
The main testing machine is a compression strength machine available in the concrete Lab. in Civil Eng. Dept. of Al- farabi University College as shown in Figure (3). This machine tests the prisms after arranging to simulate the support condition for the prisms.

![Figure 3. compressive strength testing machine with testing frame of prisms](image)

2.6.2 Compressive Strength Test
The compressive strength test of rubberized concrete is carried out using the average of three (150×150×150) mm cubes for each age (7-days and 28-days) and for each group of the four groups mentioned earlier (24 cubes of all groups) used to estimate the compressive strength according to BS1881 116-83[17]. The results of cubes for rubberized concrete (with and without Nano Silica) are given in Table (9) and table (10); Figure (4) shows the compressive strength test.
Table 9. Compressive Strength Results for 7-days curing

| Group No. | NS (%) | Cube strength $f_c$ (MPa) | Average $f_c$ (MPa) | $f'_c$ / $f'_{cNS}$ | Increasing Ratio % |
|-----------|--------|---------------------------|---------------------|---------------------|-------------------|
| 1         | 0      | 18.4                      | 18.53               | 1.0                 | 0                 |
|           |        | 18.87                     |                     |                     |                   |
|           |        | 18.34                     |                     |                     |                   |
|           |        | 20.6                      |                     |                     |                   |
| 2         | 0.5    | 22.4                      | 21.94               | 0.844               | 15.6              |
|           |        | 22.83                     |                     |                     |                   |
|           |        | 26.4                      |                     |                     |                   |
| 3         | 1      | 25.8                      | 25.91               | 0.715               | 28.4              |
|           |        | 25.58                     |                     |                     |                   |
|           |        | 30.97                     |                     |                     |                   |
| 4         | 1.5    | 34.15                     | 33.05               | 0.56                | 43.9              |
|           |        | 34.03                     |                     |                     |                   |

Table 10. Compressive Strength Results for 28-days curing

| Group No. | NS (%) | Cube strength $f_c$ (MPa) | Average $f_c$ (MPa) | $f'_c$ / $f'_{cNS}$ | Increasing Ratio % |
|-----------|--------|---------------------------|---------------------|---------------------|-------------------|
| 1         | 0      | 20.52                     | 20.84               | 1                   | 0                 |
|           |        | 21.1                      |                     |                     |                   |
|           |        | 20.9                      |                     |                     |                   |
|           |        | 22.66                     |                     |                     |                   |
| 2         | 0.5    | 25.3                      | 24.28               | 0.86                | 14                |
|           |        | 24.9                      |                     |                     |                   |
|           |        | 26.95                     |                     |                     |                   |
| 3         | 1      | 29.26                     | 28.45               | 0.73                | 26                |
|           |        | 29.12                     |                     |                     |                   |
|           |        | 36.08                     |                     |                     |                   |
| 4         | 1.5    | 35.7                      | 35.86               | 0.58                | 41.8              |
|           |        | 35.82                     |                     |                     |                   |

$f'_c$ = Average compressive strength of reference rubberized concrete 0% NS cube  
$f'_{cNS}$ = Average compressive strength of rubberized concrete cubes (with NS ratio)
2.6.3 Flexural Strength Test:
In order to represent the flexural strength of Bridge girder a model can be simulated and tested in the Lab. Flexural strength (modulus of rupture) tests are carried out in accordance with ASTM C78-04. The flexural strength tests are made on three (500×100×100 mm) beam specimens for each group loaded at two points as shown in Figure (5). Results shown in table (11).

The following equation is used to determine the flexural strength of concrete:

\[ \text{Experimental } f_r = \frac{P_L}{b d^2} \quad \text{(ASTM C78-04)} \]

where:
$f_r$: modulus of rupture (MPa).
$P$: maximum applied load (failure load) (N).
$L$: span length (mm).
$b$: width of the specimen (mm).
$d$: depth of the specimen (mm).

**Table 11. Values of Modulus of Rupture**

| Group No. | NS (%) | Modulus of Rupture (MPa) $f_r$ | Average $f_r$ (MPa) | $f_r'/f_{rNS}$ | Increasing Ratio% |
|-----------|--------|-------------------------------|---------------------|----------------|------------------|
| 1         | 0      | 3.4                           | 3.85                | 3.58           | 1                | 0                |
|           |        | 3.5                           |                     |                |                  |
|           |        | 3.95                          |                     |                |                  |
| 2         | 0.5    | 3.91                          | 3.91                | 3.95           | 0.906            | 9.36             |
|           |        | 4                             |                     |                |                  |
|           |        | 4.22                          |                     |                |                  |
| 3         | 1      | 4.28                          | 4.21                | 0.85           | 14.96            |
|           |        | 4.13                          |                     |                |                  |
|           |        | 4.65                          |                     |                |                  |
| 4         | 1.5    | 4.89                          | 4.89                | 0.732          | 26.7             |
|           |        | 5.15                          |                     |                |                  |

$f_r$ = Modulus of Rupture of concrete prisms (without NS) (MPa)
$f_{rNS}$ = Modulus of Rupture of rubberized concrete prisms (with NS ratio) (MPa)

**Figure 5. Flexural strength test**

3. Results and Discussion:

3.1 Compressive strength test Results:
The compressive strength test for rubberized concrete divided into two parts, first part done after 7 days of curing, and the second part done after 28 days of curing, both tests show that the compressive strength of rubberized concrete with NS is much higher than rubberized concrete without NS and it increases as the NS ratio increases. The best results of the three ratios of NS was recorded with the 1.5% as a partial replacement of cement with increasing ratio about 44% comparing to rubberized
concrete without NS to reach average of 34 MPa while it was average of 18.5 Mpa for RC without NS, the other two ratios of NS (0.5% and 1.0% ) gives (15.6% and 28.4% ) as increasing ratio respectively for the 7-days age concrete , the 28-days compression test gives a very close values of increasing ratio . Figures (6) (7) shows the relationship between NSR% and average compressive strength (Mpa) for 7-days age and 28-days age respectively and between NSR% and increasing ratio.

![Figure 6.](image)

**Figure 6.** comparison of compressive strength between rubberized concrete without NS and Rubberized concrete with three different ratios of NS at 7-days age and 28- days age.
3.2 flexural strength test Results:
The flexural strength test for rubberized concrete prisms without NS and that with NS shows that the modulus of rupture of rubberized concrete with NS is much higher than rubberized concrete without NS and it increases as the NS ratio increases. The best results for the three ratios was the 1.5% NS as a partial replacement of cement with increasing ratio of 26.7% comparing to the reference rubberized concrete (without NS) given average of 4.89 Mpa compared to 3.58 Mpa for reference the other two ratios of NS (0.5% and 1.0% ) gives (9.36% and 14.96% ) as increasing ratio respectively. Figure (8) and Figure (9) shows the relationship between NSR% and average flexural strength (Mpa).
3.3 Case Study

In order to check the suitability of the concrete maintained in this study, a case study of bridge girder will be presented by taking girder for bridge with length 20m and cross section dimensions (400x900)mm as following by using SAP2000 program:

- Case 1: with compressive strength 21mPa (without treatment). The deflection of girder will be 72mm.
- Case 2: with compressive strength 36mPa (with treatment). The deflection of girder will be 55mm.
- Which means that the deflection improvement will be 24% as shown in the following Figure (10):

Figure 10. Deflection reduction due to compressive strength increasing.
4. Conclusions
Depending on the test results of the experimental program, the following conclusions are obtained:
- The rubberized concrete cubes with NS shows an obvious increasing in compression strength $f_{cu}$ in both age’s 7-days and 28-days reaches 44% increasing ratio to give a maximum $f_{cu}$ equals to 35 MPa at NSR 1.5% as a partial replacement of cement.
- The increasing in strength was highest in early ages more than increasing in lately ones
- The rubberized concrete with nano silica shows increasing in flexural strength also but with less increasing ratio comparing to compression strength increasing ratio
- It was noticed that nano silica improved the workability and water absorption of the mix due to pozzolanic behavior that makes NS works as a binder and admixture at the same time
- The failure pattern of cubs and prism shows high ductility due to rubber aggregate in concrete.
- This study is maintained a lightweight concrete with high strength suitable for bridge construction that it is providing suitable loadings on the bridge foundation by decreasing the deflection with 24%.

5. Recommendations for further work:
The following areas of research concerning rubberized concrete with NS remain relatively unexplored and could form the basis of future research:
- More experimental testing should be carried out on fresh rubberized concrete with nano silica properties such as workability as well as studies about durability, sustainability and heat resistance.
- Detailed study of the flexural and shear behavior of rubberized concrete with NS in structural elements such a beam, column and slab should be investigated.
- Using other different types of concrete with rubber aggregate and nano silica such as high strength concrete, self-compacted concrete, steel fiber reinforced concrete, foam concrete ...etc.
- Studying the effect of other types of applied loads, like using repeated load and impact loading.

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