Influence of Nanoclay on the Behavior of Reinforced Concrete Slabs

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Abstract: the impact of using various percentage of nanoclay on the mechanical properties of concrete and on the flexural capacity of reinforced concrete two-way slabs was achieved in this study. The percentage of nanoclay content are (0%, 2%, 4%, 6%, 8%, 10%) weight percent of cement, and in addition to the use of polypropylene content of 1.5%. The investigated mechanical properties of concrete were compressive strength, splitting tensile strength and flexural strength. Six specimens of RC two way slabs were cast using those various content of nanoclay, the slabs were simply supported condition and under uniform load. Test indicated revealed significant improvement in the mechanical properties of concrete by using nanoclay due to its high pozzolanic activity which verifies the higher amount formation of C-S-H gel in the due to the presence of nanoparticles. When nanoclay proportion increased from 2% to 8%, the compressive strength increased about 3%, and 12.4%, respectively for samples with polypropylene equals 1.5%. While the splitting tensile strength increased by 4% up to 39.4% when using the same nanoclay proportion about 2% to 8%, respectively. The flexural modulus of rupture increased by 6%, and 36%, respectively for the same nanoclay proportion and polypropylene fiber content. The ultimate load capacity of the RC slabs increased by (12.5%) up to (66%) when the nanoclay content increased from (2% to 8%). However, using 10% nanoclay reduced the strength of the slab. In addition, different failure modes was observed for the slabs when using different percentage of nanoclay content.

Keywords: flexural, compressive strength, concrete, Nano clay, splitting

1. Introduction:
Nanomaterials are substances which one of its dimensions or more does not exceed (1 nanometer). They are considered very reactive due to the small size of the particles and large surface area. For concrete, using nanomaterials as a supplementary cementitious material reduces the permeability and enhances the strength of concrete mix when compared to conventional concrete. Because of its high reactivity, small amount of nanomaterials product causes to reduce the replacing of cement component in the mixture in addition to the economic benefit regarding its less cost. Cementitious compounds are resulted from the chemical reaction of pozzolans with the released Calcium hydroxide during hydration. Because of the properties nanoparticles related to their dimensions, the production of a dense cement matrix having larger amount of calcium silicate hydrate with less calcium hydroxide as a result of the chemical process is more effective [1].
Clay particles at the nano size possess some unique characteristics. The lamina form of nano-clay particles has a tiny size of 70 to 150 nm in width and 1 nm thickness and an aspect ratio of 100 to 150 strengthens the properties of the mortar contains nano-meta-kaolin (NMK). NMK is a valuable
pozzolanic material; it is a thermally activated aluminosilicate material obtained by firing kaolin clay within a range of temperature equals 700–850 °C [2, 3, 4, and 5].

In recent years, a lot of research work in the nanotechnology field has been carried out. Nanotechnology has applications in many aspects of science and technology taking the advantage of the molecular level to produce systems compound of nano-materials which needs to fabricate new devices dealing with that size range. [6].

Nano clay is a fine mineral admixture can be added to cement mortar in nanostructures systems in recent decade. Research on nano-clay particles promises to modify the properties of concrete regarding the chloride penetration resistance, workability and reducing porosity [7, 8].

Other types of additives have also been used for improving the mechanical properties of concrete using polypropylene fibers. Basic concern when using fibers is how to provide full bond developed between the fibers and the matrix. It was found that the fiber decreases the transferability of tensile stresses within the crack which avoids the big crack opening. Therefore the fiber length plays a main role to bridge the cracks which avoid fractures and sudden failure. According to most manufacturers, the value of polypropylene content that recommended to use with mixtures is 0.10% by the total volume equals to 0.8890 to 0.949 kg per cubic meter). The maximum volume percentage of polypropylene with fiber used by researchers is 7.0 percent. It was found that using 2.0 percent volume of polypropylene fiber is not preferred because of the constructability problems. Besides it obtained that there is no need to adjust the mixture proportions when using fiber volumes not more 0.5 percent [9].

2. Experimental Part
2.1 Used Materials

2.1.1 Cement: Local produced of OPC (ordinary Portland cement) was used and cement test results have been found to satisfy the Iraqi specification No.5/1984 [10].

2.1.2 Fine Aggregates: Local glass sand(Fine silica) was used with fineness modulus was 2.220.

2.1.3 Coarse Aggregate: A crashed coarse aggregate of pass through sieve 12.5mm was achieved in the experiments. The grading is shown in table (1) and conformed to IQS 45/1945. The physical properties including specific gravity, bulk density, absorption, and the percentage of sulfat content of the crashed coarse aggregate are listed in Table (2).

| Sieve Size (mm) | Passing Percentage | IQS 45/1945 |
|-----------------|--------------------|-------------|
| 12.50           | 100.0              | 100         |
| 10.0            | 86.0               | 85-100      |
| 4.750           | 8.0                | 0-25        |
| 2.360           | 0.0                | 0-5         |

| Properties      | Result     | IQS 45/1945 |
|-----------------|------------|-------------|
| GS              | 02.68      | -           |
| SO3             | 00.05 %    | ≤ 0.10 %    |
| Abs.            | 00.60 %    | -           |
| Bulk Density (kg/m3) | 1565   | -           |

2.1.4 Steel Reinforcement: steel reinforcing bar of 6mm was used in this study. The yield strength was 612 MPa while the ultimate strength was 756 MPa.
2.1.5 Nanoclay: Nano metakaolin was brought from (Senaa desert-Egypt) with the help of Middle East Mining Investments Company MEMCO. According to previous investigation NMK was calcinations for reactivation clay. The calcinations temperature and the calcinations time selected for this study were 750 °C and 2 hr. respectively. The nano clay material used in this work has a surface area ≈ 480000 cm²/g and average dimensions of 200x100x20 nm. Table (3) gives the chemical composition of nanoclay.

| Chemical content | W% |
|------------------|----|
| SiO2             | 45.5 |
| Al2O3            | 37  |
| Fe2O3            | 0.2 |
| TiO2             | 0.15|
| CaO              | 0.01|
| MgO              | 0.02|
| Na2O             | 0.03|
| K2O              | 0.07|
| LOI              | 12.5|

2.1.6 Polypropylene: the density of PP in present study was 0.902 g/cc and the melting flow was 3.0 g/10.0 mins at 02.16 Kg load /230 °C also the temperature of process was 230-260 °C; see Table (4)

| Diameter mm | Length mm | Aspect Ratio L/D | Tensile Strength MPa | Specific gravity |
|-------------|-----------|-------------------|-----------------------|-----------------|
| 00.0445     | 6.20      | 139.33            | 308                   | 1.33            |

2.1.7 Water: Tap water was used in concrete mixing and treatment for all control and slabs.

2.2 Mix Proportions
Six specimens of different concrete mixtures proportions were designed with a constant water cement ratio equals 0.24, cement content is 350 kg/m³, sand content is 720 kg/m³ and gravel content equals 1300 kg/m³. Table (5) lists the proportions of concrete mixture and binder paste used for the specimens.

2.3 Concrete Preparation
The properties of concrete were tested. Compressive Strength Values were obtained according to BS 1881 - Part 116) [11] on samples 150 x 150 x 150 mm in 28 days of treatment. The mitotic tensile strength was measured at the age of 28 days using cylindrical samples with dimensions of 100 mm and a diameter of 200 mm according to ASTM C496 [12]. ASTM C293 compatible bending tests were applied to 50 x 50 x 200 mm [13] prisms. Each result represented an average of three samples for each concrete mixture and all samples were treated in water until test life as shown in Figure 1.

| Specimen No. | Concrete ID | Cement kg/m³ | Sand kg/m³ | Gravel kg/m³ | Nano-clay% | P.P% | w/c |
|--------------|-------------|---------------|-------------|--------------|------------|------|-----|
| 1            | C1          | 350           | 720         | 1300         | 0          | 1.5  | 0.42|
| 2            | C2          | 350           | 720         | 1300         | 2          | 1.5  | 0.42|
| 3            | C3          | 350           | 720         | 1300         | 4          | 1.5  | 0.42|
| 4            | C4          | 350           | 720         | 1300         | 6          | 1.5  | 0.42|
| 5            | C5          | 350           | 720         | 1300         | 8          | 1.5  | 0.42|
| 6            | C6          | 350           | 720         | 1300         | 10         | 1.5  | 0.42|
2.4 Reinforced Concrete Slabs
Six slabs were S.S. RC slabs were tested up to ultimate capacity at Mustansiriyh University with rectangular in shape of (600x1000x70) mm, width, long and thickness, respectively and reinforced with $\phi 6@120$mm steel bars along the lateral and longitudinal directions. The specimens had different values of nanoclay content (0, 2, 4, 6, 8, 10 %) of cement weight. Sand bags were placed at the top compression face of the slabs to represent the application of the uniform load. A concentrated load was applied gradually at the mid-span of the slab by hydraulic universal machine. The slab details as shown in Figure 2.

3. Results and Discussion
3.1 Mechanical Properties
Values of compressive strength were improved for samples about 3%, 7% ,10% and 12.4% when nanoclay was increased from 0 to 8% with Polypropylene content of 1.5% in concrete mix as shown in Figure (3). The increase in the compressive strength can be attributed to the proper available conditions for chemical reaction in addition to the uniform dispersion of nanoclay particles through the wet mixing. The splitting tensile strength values increased by 4%, 19%,30.6% and 39.4% as nanoclay content increases by 2%, 4%, 6% and 8%, respectively. For the flexural strength values, it was observed that they increased by 4.6%, 20%, 28% and 36% as nanoclay increases to 2%, 4%, 6% and 8%, respectively, see Table (6). Figures (4) and (5) show the effect of percentage of nanoclay content in the mixture by weight on the splitting strength and flexural strength, respectively.
Table (6) Compressive, Splitting and Flexural Strength Results of Concrete

| Specimen No. | Concrete ID | Compressive Strength, MPa | Splitting Tensile Strength, MPa | Flexural Strength, MPa |
|--------------|-------------|---------------------------|-------------------------------|-----------------------|
| 1            | C1          | 52.32                     | 7.96                          | 9.36                  |
| 2            | C2          | 53.8                      | 8.32                          | 9.92                  |
| 3            | C3          | 55.9                      | 9.54                          | 11.24                 |
| 4            | C4          | 57.5                      | 10.42                         | 12.02                 |
| 5            | C5          | 58.8                      | 11.16                         | 12.76                 |
| 6            | C6          | 55.6                      | 9.63                          | 11.5                  |

The improvement of mechanical properties of the cementitious composites reinforced by nanoparticles may be attributed to some reasons as:

1) Nanoparticles act as a nucleus for tightly bonding with cement hydrates when distributed in cement paste, and the higher particle activity has improved the hydration of cement, which is suitable for strength slurry [14,15].

2) the nanoparticles inhibit crystals growth among the formed hydrate products, which lead to improve the performance of the cement paste [15,16].

Figure (3): Impact of Percentage of Nanoclay on Compressive Strength

Figure (4): Impact of Percentage of Nanoclay on Splitting Tensile Strength

Figure (5): Impact Percentage of Nanoclay Modulus of Rupture

3.2 load carrying capacity and the failure mode of 2 way slabs

Table 7 shows the experimental results of the load carrying capacity and the failure mode for the nanoclay RC two way slabs. It was determined that the flexural performance of the slabs enhanced by the addition of nanocaly, the optimum percentage of nanoclay content was found to be for the slab with 8% nanoclay content. Figure 6 shows the failure mode of the slabs, all slabs failed under flexural with cracks along the longitudinal direction, the depth of the cracks decreases with the increase of nanoclay content except for that with 10% nanoclay, which showed brittle failure with concrete crushing.
Table (7): load carrying capacity and the failure mode

| Slab No. | Load Carrying Capacity KN | Failure Mode       |
|----------|---------------------------|-------------------|
| NC0      | 85                        | Flexural failure  |
| NC2      | 92                        | Flexural failure  |
| NC4      | 105                       | Flexural failure  |
| NC6      | 122                       | Flexural failure  |
| NC8      | 135                       | Flexural failure  |
| NC10     | 117                       | Concrete Crushing |

Figure (6): Failure Surface of Reinforced Concrete Two Way Slabs

4. Conclusions
According to the results obtained from the experimental work, the following conclusions can be drawn:

1. Because of the accelerated formation of the C-S-H gel, as a result of an increase in the amount of crystalline Ca (OH) 2, the mechanical properties have been significantly improved in mixtures containing a nanostructure.

2. Increasing the content of binder improves the performance of the concrete mixture.

3. The optimum value of nanoclay percentage content is 8% which gives the highest values of strength values.

4. The maximum values of the compressive, splitting and flexural strengths are 58 MPa, 11.16MPa and 12.76 MPa, respectively achieved at 8% nanoclay percentage content.

5. The increasing of nanoclay content led to increase in experimental ultimate load capacity of slab and a significant improvement was obtained for 8% nanoclay content.

6. The failure mode of the slabs was flexural, the presence of nanoclay enhances the behavior of the slab by decreasing the depth of the cracks. However, increasing the nanoclay content to 10% changed the failure to brittle.

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