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# Influence of nano materials on flexural behavior and compressive strength of concrete

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**KEYWORDS**

Nano silica;
Nano clay;
Concrete;
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Hybrid

**Abstract** This paper investigates the effect of nano particles on the mechanical properties at different ages of concrete. Different mixtures have been studied including nano-silica (NS), nano-clay (NC) or both NS and NC together with different percentages. Mechanical properties have been investigated such as compressive and flexure strength through testing concrete prisms 40, 40 and 160 mm at 7, 28 and 90 days in order to explore the influence of these nano particles on the mechanical properties of concrete. Results of this study showed that nano particles can be very effective in improving mechanical properties of concrete, nano-silica is more effective than nano clay in mechanical properties and wet mix gives higher efficiency than dry mix. Exceeding a certain percentage of nano particles in concrete negatively affects the mechanical properties. Also, binary usage of nano particles; (NS + NC) had a remarkable improvement appearing in concrete compressive strength than using the same percentage of single type of nano particles. This improvement can be attributed to the reaction of nano materials with calcium hydroxide $Ca(OH)_2$ crystals, which are arrayed in the interfacial zone (ITZ) between hardened cement paste and aggregates, and produce C- S-H gel and the filling action of nano particles which cause more densified microstructure. A percent of 3% nano particles consisting of 25% NS and 75% NC gave the highest mechanical properties representing in both compressive and flexure strengths among other percentages.


## Introduction

During recent years, nano technology is developing with an ascending rate. Due to the new uses of nano particles there is an interest in the investigation of the effect of nano-particles; especially in concrete and cement mortar. Many of the available studies have focused on the effect of Nano-$SiO_2$ on the properties of hardened cement paste, cement mortar and/or concrete. Qing et al. [1] experimentally investigated the effects of Nano-$SiO_2$ on the properties of hardened cement paste. Jo et al. [2] studied the influence of Nano-$SiO_2$ on the

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characteristics of cement mortars. Li et al. [3] investigated the effects of Nano-$SiO_2$ and Nano-$Fe_2O_3$ on mechanical properties of cement mortars. Li [4] studied the influence of Nano-$SiO_2$ on mechanical properties of high volume fly ash concretes. Said et al. [5] studies the properties of concrete incorporating nano silica with 3% and 6% percentage by weight of cement. The results of these studies showed that Nano-$SiO_2$ can improve the mechanical properties of hardened cement paste and cement mortar. Morsy [6] experimentally investigate that compressive and tensile strength of the cement mortars with nano clay is higher than that of the plain cement mortar with the same w/b ratio. Ammar [7] studied the effect of nominal size of nano silica on the compressive and tensile strength of concrete. Ozyildirim et al. [8] investigated how nanomaterial improved permeability and strength of concrete and found that very little amount of nano materials like nano silica and nano clay in concrete can improve the compressive strength and permeability of concrete.

Zaki et al. [9] studied the use of nano composites to develop the micro structure and the impermeability of high strength concrete and found that the use of nano silica improved the impermeability of high strength concrete.

Shekari and Razzaghi [10] studied the influence of nano particles on mechanical properties and durability of concrete with constant content of Nano-$ZrO_2$ (NZ), Nano-$Fe_3O_4$ (NF), Nano $TiO_2$ (NT) and Nano-$Al_2O_3$ (NA) added to concrete mixtures. Results of this study showed that nano particles can be very effective in improvement of both mechanical properties and durability of concrete. Results of this study indicated that the Nano-$Al_2O_3$ is the most effective nano-particle in improvement of mechanical properties of high performance concrete.

Zaki and Ragab [11] studied how nano technology can change concrete industry and found that the optimum amounts of nano silica is 0.5% which enhanced the micro structure up to one year. Shebl et al. [12] aimed to develop the effect of variable ratio of nano silicate (NS) replacement on the properties of blended white cement pastes as compared with the control paste through the measurements of indirect tensile strength (ITS). It was found that, increasing the replacement content of unactivated NS up to 2%, improved the ITS by about 40% compared with the control paste. Also, the results showed that increasing the replacement content generally increases water absorption and the porosity of blended white cement pastes. Mohammed [13] investigates the influence of using different cement blends on the concrete properties incorporating nano materials. There was a significant positive effect of using ternary blends on the different mechanical properties.

## Experimental program

The experimental program consists of casting 24 mixes of concrete with variable nano material percentages from 0% up to 10% as a replacement of cement and hybrid mix nano material percentages from 0% up to 100% for each type. The experimental mold consists of nine prisms $40 \times 40 \times 160$ mm to be tested for flexure and compressive strength at 7, 28 and 90 days. The legend of specimen refers to specimen number followed by% NS then %NC and finally W for wet mixing for nano materials or D for dry mixing for nano materials with cement and silica fume as shown in Table 1.

## Concrete mixtures

The concrete mix of this study consisting of ordinary cement (42.5N) complies with EN-BS-(196-5-2009) [14] obtained from Suez cement factory in Egypt, silica fume was obtained from the Egyptian Company for Iron Foundries, nano-silica is exported from Germany and nano clay was given by the Mid-

**Table 1** Mix proportions of experimental specimens.

| Mix | Cement (g) | Dolomite (g) | Sand (g) | Silica fume (g) | Water (g) | Admixture (g) | Nano Silica (g) | Nano Clay (g) |
|---|---|---|---|---|---|---|---|---|
| S1-control | 500.0 | 740 | 550 | 100 | 180 | 12.5 | 0.00 | 0.00 |
| S2-0.5 NS–0 NC (W) | 497.5 | 740 | 550 | 100 | 180 | 12.5 | 2.50 | 0.00 |
| S3-0.75 NS–0 NC (W) | 496.25 | 740 | 550 | 100 | 180 | 12.5 | 3.75 | 0.00 |
| S4-1 NS–0 NC (W) | 495.0 | 740 | 550 | 100 | 180 | 12.5 | 5.00 | 0.00 |
| S5-1.25 NS–0 NC (W) | 493.75 | 740 | 550 | 100 | 180 | 12.5 | 6.25 | 0.00 |
| S6-1.5 NS–0 NC (W) | 492.5 | 740 | 550 | 100 | 180 | 12.5 | 7.50 | 0.00 |
| S7-0 NS–1 NC (D) | 495.0 | 740 | 550 | 100 | 180 | 12.5 | 0.00 | 5.00 |
| S8-0 NS–3 NC (D) | 485.0 | 740 | 550 | 100 | 180 | 12.5 | 0.00 | 15.00 |
| S9-0 NS–5 NC (D) | 475.0 | 740 | 550 | 100 | 180 | 12.5 | 0.00 | 25.00 |
| S10-0 NS–7 NC (D) | 465.0 | 740 | 550 | 100 | 180 | 12.5 | 0.00 | 35.00 |
| S11-0 NS–10 NC (D) | 450.0 | 740 | 550 | 100 | 180 | 12.5 | 0.00 | 50.00 |
| S12-0 NS–1 NC (W) | 495.0 | 740 | 550 | 100 | 180 | 12.5 | 0.00 | 5.00 |
| S13-0.25 NS–0.75 NC (W) | 495.0 | 740 | 550 | 100 | 180 | 12.5 | 3.75 | 1.25 |
| S14-0.75 NS–2.25 NC (W) | 485.0 | 740 | 550 | 100 | 180 | 12.5 | 11.25 | 3.75 |
| S15-1.25 NS–3.75 NC (W) | 475.0 | 740 | 550 | 100 | 180 | 12.5 | 18.75 | 6.25 |
| S16-0.5 NS–0.5 NC (W) | 495.0 | 740 | 550 | 100 | 180 | 12.5 | 2.50 | 2.50 |
| S17-1.5 NS–1.5 NC (W) | 485.0 | 740 | 550 | 100 | 180 | 12.5 | 7.50 | 7.50 |
| S18-2.5 NS–2.5 NC (W) | 475.0 | 740 | 550 | 100 | 180 | 12.5 | 12.50 | 12.50 |
| S19-0.75 NS–0.25 NC (W) | 495.0 | 740 | 550 | 100 | 180 | 12.5 | 1.25 | 3.75 |
| S20-2.25 NS–0.75 NC (W) | 485.0 | 740 | 550 | 100 | 180 | 12.5 | 3.75 | 11.25 |
| S21-3.75 NS–1.25 NC (W) | 475.0 | 740 | 550 | 100 | 180 | 12.5 | 6.25 | 18.75 |
| S22-0.5 NS–0.5 NC(D) | 495.0 | 740 | 550 | 100 | 180 | 12.5 | 2.50 | 2.50 |
| S23-1.5 NS–1.5 NC(D) | 485.0 | 740 | 550 | 100 | 180 | 12.5 | 7.50 | 7.50 |
| S24-2.5 NS–2.5 NC(D) | 475.0 | 740 | 550 | 100 | 180 | 12.5 | 12.50 | 12.50 |

dle East Company in Egypt. Glenium ACE 30, Polycaboxilate-based super plasticizer was used in the concrete mixes. The percent of silica fume in each mix was 20% added to the cement. The content of Nano-particles in different specimens was ranged from 0.5% up to 10% as a replacement of the weight of cement. The maximum size of coarse aggregates was 10 mm. The mix proportions for all experimental specimens are presented in Table 1.

**Experimental procedures**

The fresh concrete was cast in $40 \times 40 \times 160$ mm prism as shown in Fig. 1(a) similar to EN (196-1/2005) [13]. The moist air room for storage of the specimens in the mould is maintained at a temperature of $(20.0 \pm 1.0)$ °C and a relative humidity of not less than 90% as shown in Fig. 1(b) for the first 24 h. After being demolded at the age of one day, all specimens were cured in water at $20 \pm 1$ °C for 7, 28 and 90 days.

**Dry mixing procedure**

Mixing of the nano particles with cement and silica fume with the target percentage at dry state using automatic mixer for 5 min, was done to obtain the best dispersion for nano particles in the dry mix as shown in Fig. 2(a), then the aggregate was added to the water with admixture and mixed for 2 min.

**Wet mixing procedure**

Cement, silica fume, fine and coarse aggregate were mixed together for 30 s. then 50% of mixing water was added to the mix. The rest 50% of mixing water was added to the nano particles and admixture and mixed together to insure dispersion of nano particles then it was added to the mix in the automatic mixer for 4 min. as shown in Fig. 2(b).

**Test procedures for hardened concrete**

The hardened concrete samples were removed from curing chamber at each of test ages of 7, 28 and 90 days and any deposit on the test faces was removed. Then the specimens were left at air for approximately 15 min. Table 2 summarizes the compressive and flexure experimental results.

**Flexure tensile test**

A flexure tensile test according to EN-196-1-2005 [14] was conducted on prism samples. For each mixture nine samples were

(a) (b)

**Fig. 1** (a): Casting concrete into specimen prism, (b): The specimen at moist air room.

(a) (b)

**Fig. 2** (a): Dry mixing procedure, (b): Wet mixing procedure.

**Table 2** Results of experimental program.

| Mix | Compressive strength (MPa) | | | Flexure strength (MPa) | | |
|---|---|---|---|---|---|---|
| | 7 days | 28 days | 90 days | 7 days | 28 days | 90 days |
| S1-control | 65.03 | 73.43 | 97.97 | 11.31 | 11.25 | 13.70 |
| S2-0.5 NS–0 NC (W) | 74.27 | 79.79 | 105.80 | 11.70 | 11.96 | 13.93 |
| S3-0.75 NS–0 NC (W) | 78.33 | 91.31 | 115.67 | 11.86 | 12.22 | 14.19 |
| S4-1 NS–0 NC (W) | 74.09 | 86.61 | 90.50 | 11.78 | 12.08 | 13.27 |
| S5–1.25 NS–0 NC (W) | 73.38 | 86.03 | 89.33 | 11.57 | 11.86 | 13.79 |
| S6-1.5 NS–0 NC (W) | 54.60 | 60.34 | 85.57 | 11.29 | 10.50 | 13.78 |
| S7-0 NS–1 NC (D) | 65.85 | 82.18 | 97.50 | 9.14 | 11.72 | 11.53 |
| S8-0 NS–3 NC (D) | 66.84 | 107.99 | 108.29 | 10.20 | 13.52 | 14.81 |
| S9-0 NS–5 NC (D) | 68.94 | 84.09 | 97.08 | 9.82 | 10.81 | 11.89 |
| S10-0 NS–7 NC (D) | 50.39 | 82.42 | 90.78 | 11.01 | 10.20 | 11.82 |
| S11-0 NS–10 NC (D) | 51.07 | 72.22 | 103.34 | 10.31 | 9.13 | 10.30 |
| S12-0 NS–1 NC (W) | 76.66 | 91.80 | 120.81 | 12.07 | 15.71 | 15.25 |
| S13-0.25 NS–0.75 NC (W) | 78.99 | 85.61 | 123.58 | 10.99 | 14.87 | 15.30 |
| S14-0.75 NS–2.25 NC (W) | 81.25 | 114.91 | 126.44 | 13.36 | 14.84 | 15.12 |
| S15-1.25 NS–3.75 NC (W) | 70.70 | 88.00 | 113.25 | 11.87 | 13.70 | 13.88 |
| S16-0.5 NS–0.5 NC (W) | 66.60 | 109.87 | 116.64 | 10.55 | 12.71 | 13.18 |
| S17-1.5 NS–1.5 NC (W) | 82.19 | 101.84 | 115.43 | 9.62 | 13.00 | 14.59 |
| S18-2.5 NS–2.5 NC (W) | 56.94 | 111.97 | 114.60 | 12.75 | 14.45 | 14.72 |
| S19-0.75 NS–0.25 NC (W) | 59.60 | 96.20 | 114.43 | 10.85 | 14.29 | 14.78 |
| S20-2.25 NS–0.75 NC (W) | 77.71 | 97.34 | 118.26 | 10.46 | 13.35 | 14.68 |
| S21-3.75 NS–1.25 NC (W) | 81.27 | 100.42 | 119.05 | 11.26 | 12.07 | 13.54 |
| S22-0.5 NS–0.5 NC(D) | 73.74 | 107.18 | 110.00 | 10.35 | 14.89 | 16.92 |
| S23-1.5 NS–1.5 NC(D) | 89.38 | 101.50 | 113.80 | 10.77 | 13.36 | 22.16 |
| S24-2.5 NS–2.5 NC(D) | 85.15 | 95.25 | 107.88 | 11.59 | 12.43 | 13.22 |

prepared and tested at a rate of 50 ± 10 N/s. The results presented herein for flexure tensile strength tests are an average of three samples of each mixture at test age (7, 28 and 90) days. The apparatus for flexure device incorporating two steel supporting rollers of (10.0 ± 0.5) mm diameter spaced (100.0 ± 0.5) mm apart and a third steel loading roller of the same diameter placed centrally in the middle of the span. The length of these rollers was 50 mm. The loading arrangement is shown in Fig. 3.

### Compression test

Compressive strength test according to EN-BS-1881-119-2011 [15] was conducted on samples. For each mixture eighteen samples were prepared and tested at a rate of 2400 ± 200 N/s. The results presented herein for compressive strength tests are an average of six samples of each mixture at test age (7, 28 and 90) days. The specimen was crushing in cone shape after compression test as shown in Fig. 4.

### Results and discussion

The effect of using nano silica (NS) on the compressive strength is presented in Fig. 5 which indicated that the effect of adding 0.5% and 0.75% dosages of nano silica in wet condition increases the compressive strength more than control mix with 14.2% and 20.5% for 7 days and 8.7% and 24.4% for 28 days and 8% and 18.1% for 90 days, respectively, these improvements are due to increase in the rate of pozzolanic reaction due to the large surface area of the nano-particles in addition to the nano-$SiO_2$ acting as a packing material and as an activator to promote pozzolanic reaction.

The effect of using nano silica (NS) on flexure strength is presented in Fig. 6 which indicated that the effect of adding

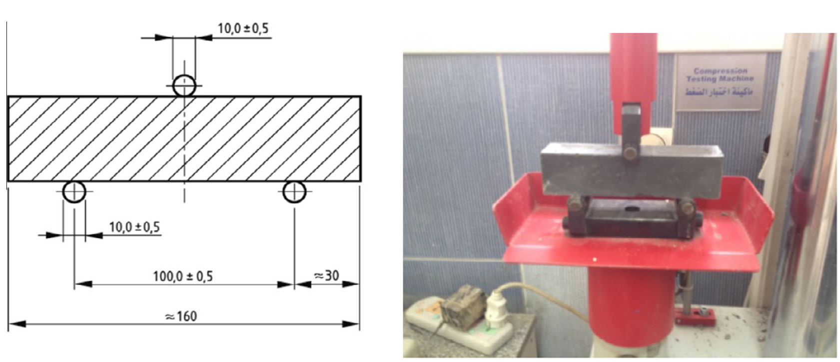


**Fig. 3** Arrangement of loading for determination of flexural strength.

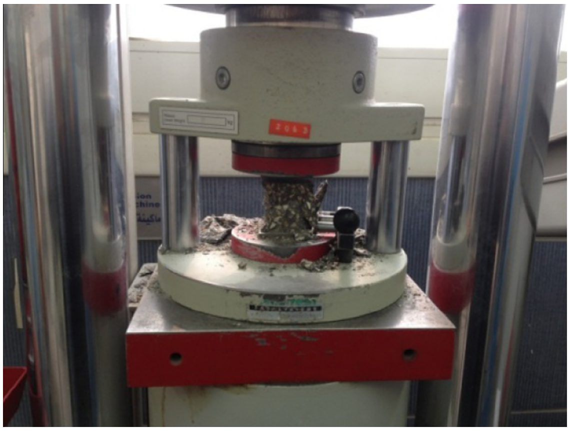

**Fig. 4** Specimen failure after compression strength test.

0.5% and 0.75% dosage of nano silica in wet condition lightly increases the flexure strength more than control mix up to 8.6% for 28 days and 3.6% for 90 days, the little increase returns to the minor effect of increased compressive strength on the flexure behavior of concrete.

Adding an additional percentage of nano silica (NS) on compressive and flexure strength is presented in Figs. 7 and 8 respectively, the Figures show that increasing the percentage of nano Silica increases the compressive strength of concrete and flexure strength up to 0.75% NS after this percentage the relation descending up to 1.5% NS, this phoneme may be due to the agglomeration of these particles because they cannot be dispersed uniformly due to their large surface area.

The effect of using nano Clay (NC) on the compressive strength is presented in Fig. 9 which indicated that the effect of adding 1% and 3% dosage of nano clay in dry condition increases the compressive strength more than control mix with

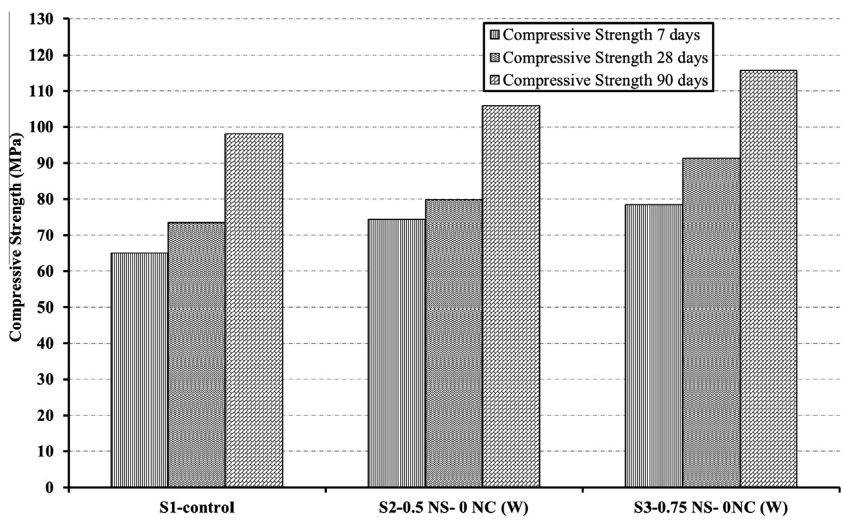


**Fig. 5** Effect of Nano silica on compressive strength.

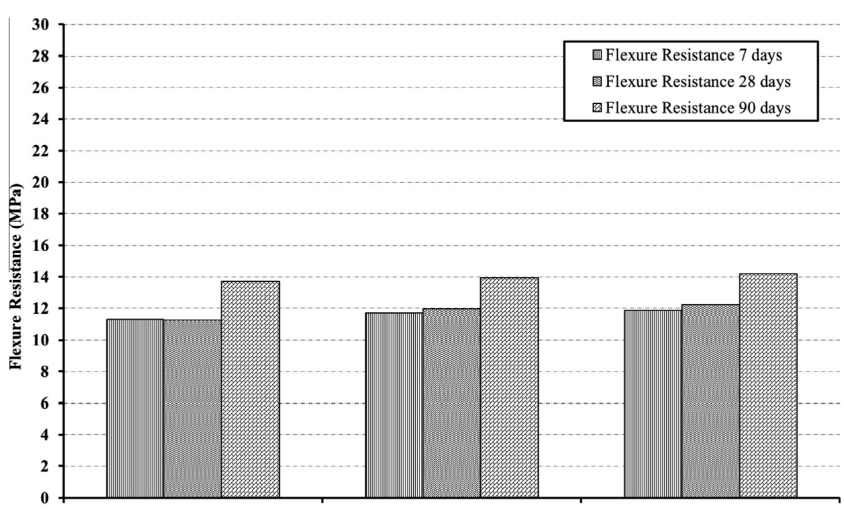


**Fig. 6** Effect of Nano silica on flexure strength.

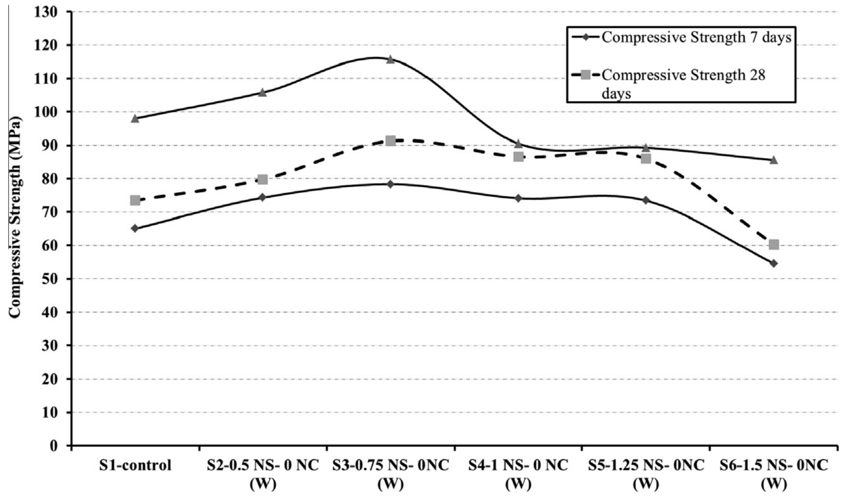


**Fig. 7** Optimum percentage of Nano silica for compressive strength.

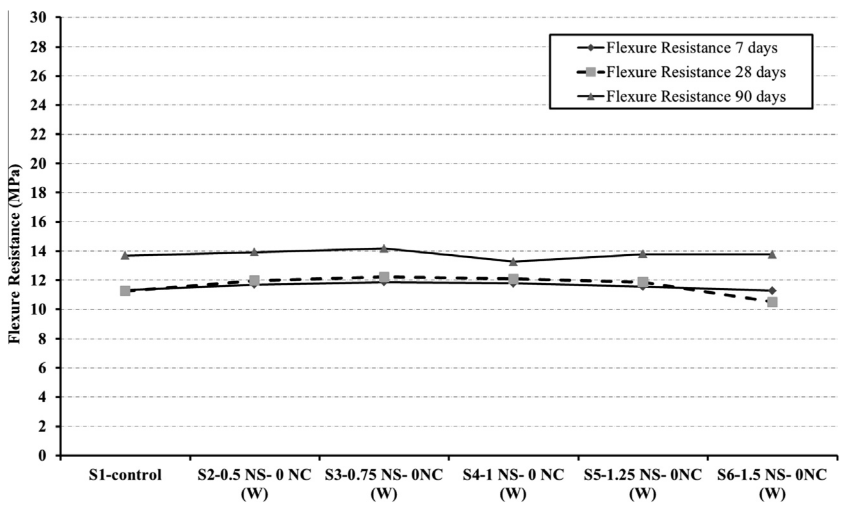


**Fig. 8** Optimum percentage of Nano silica for flexure strength.

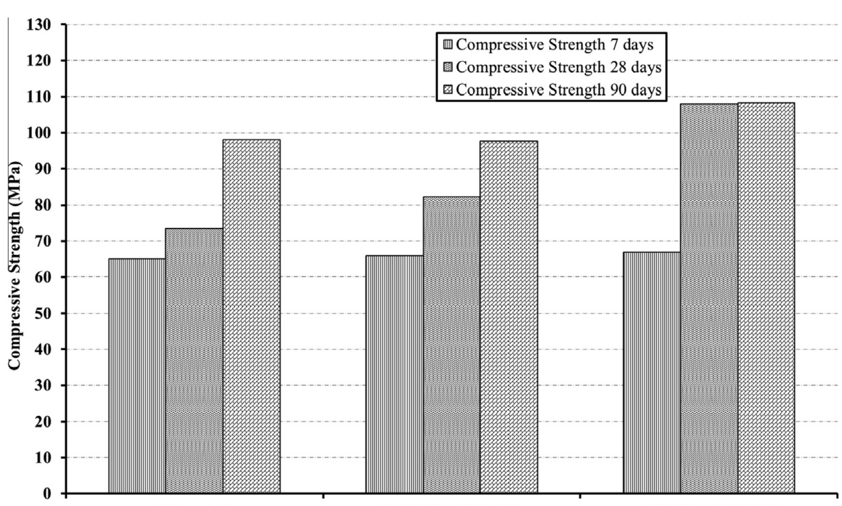


**Fig. 9** Effect of Nano clay on compressive strength.

1.3% and 2.8% for 7 days, 11.9%, 47.1% for 28 days and −0.48% and 10.6% for 90 days, respectively, This effect in the compressive strength is due to the filling action of nano clay particles in the transition zone.

The effect of using nano Clay (NC) on the flexure strength is presented in Fig. 10 which indicated the effect of adding 1% and 3% dosages of nano clay in dry condition lightly increases the flexure strength more than control mix for tested days up to 8.1% at 90 days.

The effect of adding higher percentages of nano clay (NC) at dry conditions on compressive and flexure strength is presented in Figs. 11 and 12 which indicated that the optimum percentage of NC is 3% while at 90 days a percentage of 10% of nano clay has an improvement of nearly 3% in compressive strength but it had a negative economical crises. This improvement at 10% NC may be due to the high dosage of NC whose density the cement paste voids and improves the microstructure.

The effect of using 1%, 3% and 5% as a replacement of cement by hybrid nano particles NS and NC with mix percentage 0–100 on the compressive strength is presented in Figs. 13, 15 and Fig. 17 respectively, while flexural resistance is shown in Figs. 14, 16 and 18.which indicated the hybrid mix is better than the same percentage of the nano particles and also the optimum hybrid ratio for economic and better improvement in compressive strength is 25% NS and 75% NC taking into consideration the high price of NS compared with NC which is much cheaper and locally and easily synthesized in Egypt.

1% Hybrid nano with mix of 25% NS and 75% NC improves the compressive strength with 21.5% at 7 days, 16.6% at 28 days and 26.1% at 90 days than control mix. Also improves the compressive strength with 6.6% at 7 days and 36.6% at 90 days than 1% nano silica mix and improves the compressive strength with 20% at 7 days, 4.2% at 28 days and 26.8% at 90 days than 1% nano clay dry mix as shown in Fig. 13. This improvement can be referred to the filler action of nano silica and nano clay and suitable mix percentage also the optimum percentage of NS which had a higher surface area which improves the chemical reaction due to the pozzolanic activity, additional Calcium Silicate Hydrates are formed to

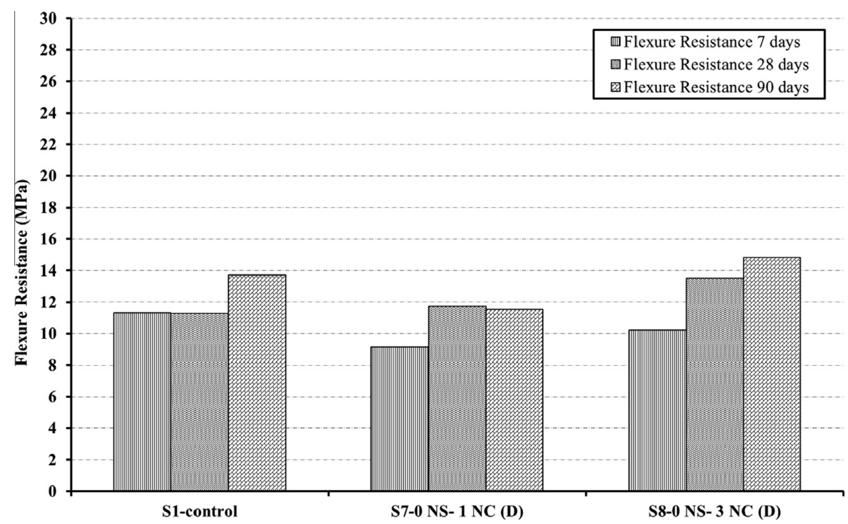


**Fig. 10** Effect of Nano clay on flexure strength for tested specimen.

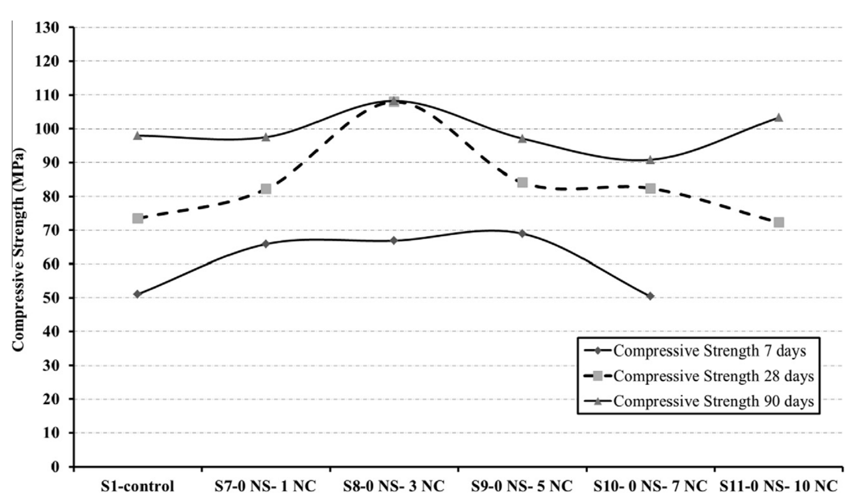


**Fig. 11** Optimum percentage of Nano clay for compressive strength.

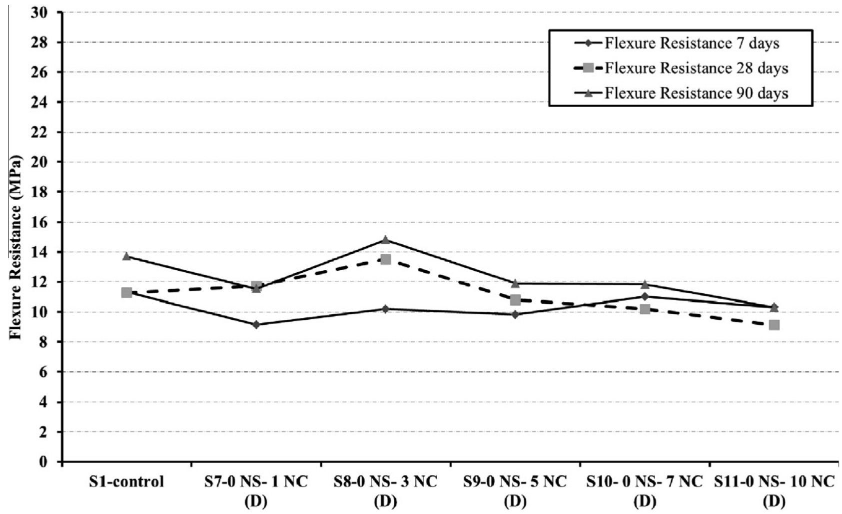


**Fig. 12** Optimum percentage of Nano clay for flexure strength.

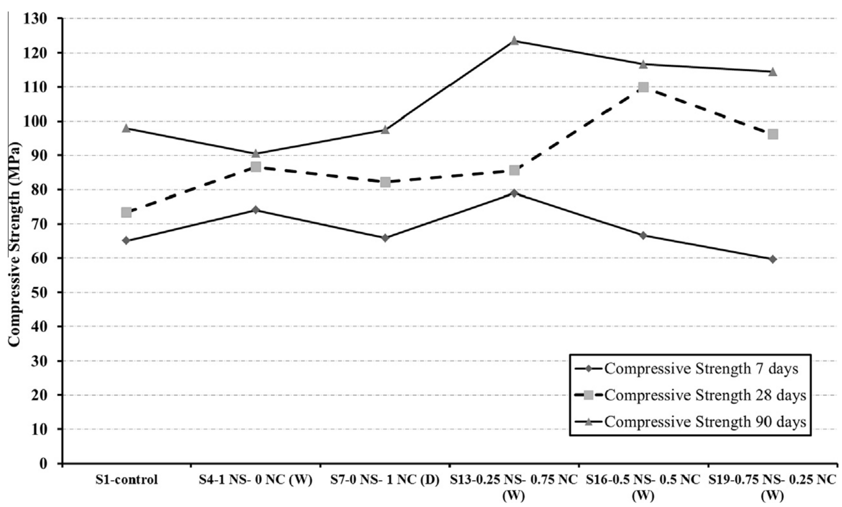


**Fig. 13** Effect of 1% hybrid Nano particles on Compressive Strength.

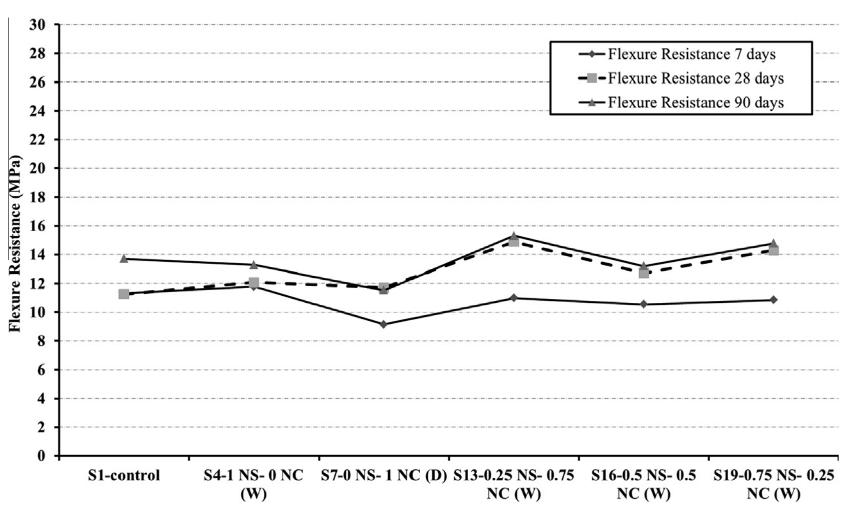


**Fig. 14** Effect of 1% hybrid Nano particles on flexure strength.

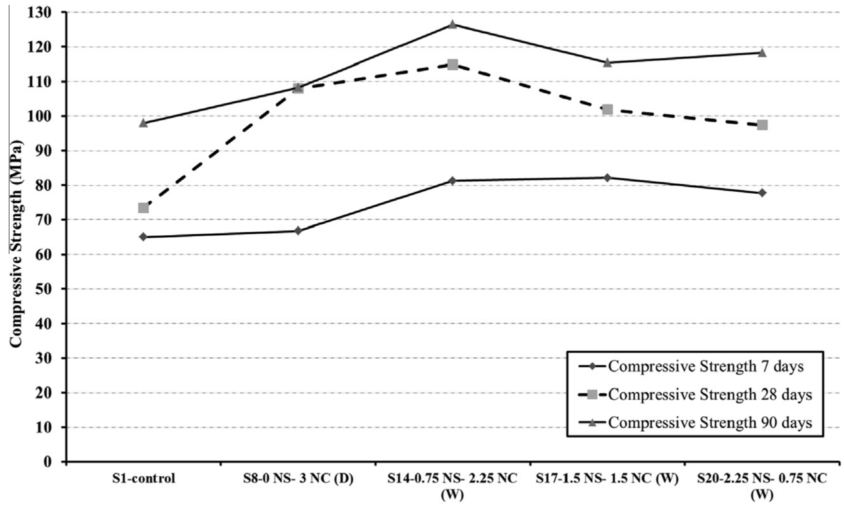


**Fig. 15** Effect of 3% hybrid Nano particles on compressive strength.

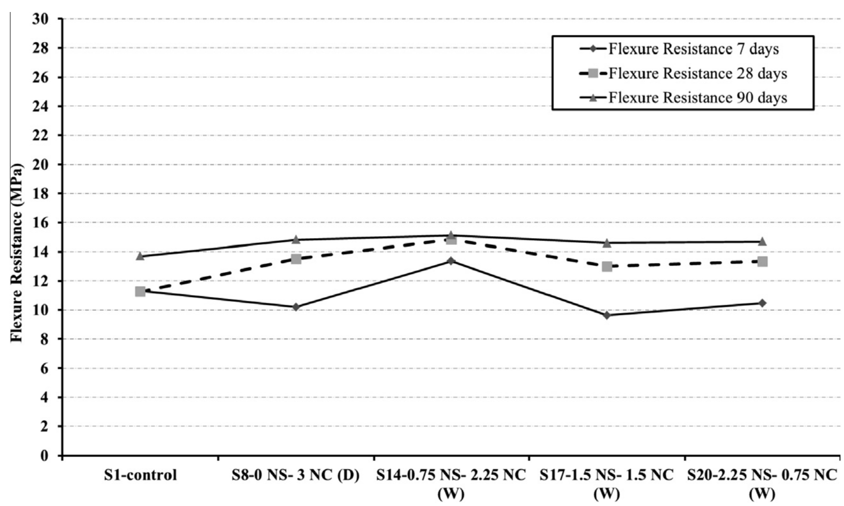


**Fig. 16** Effect of 3% hybrid Nano particles on flexure strength.

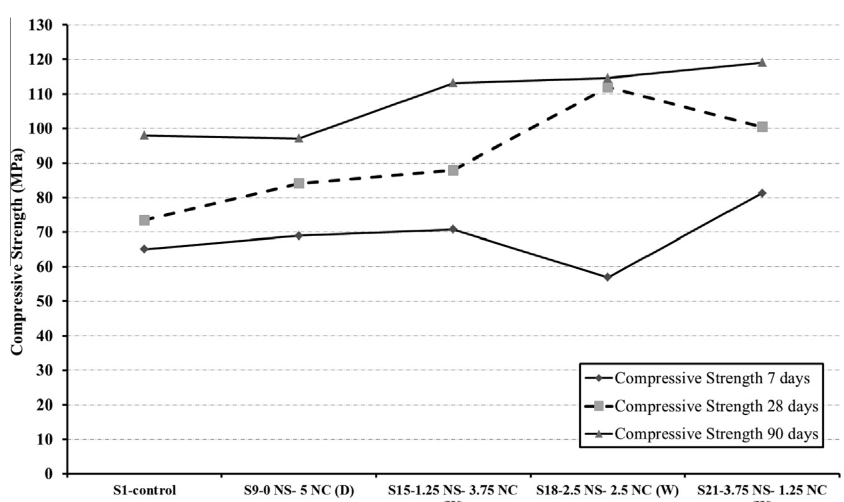


**Fig. 17** Effect of 5% hybrid Nano particles on compressive strength.

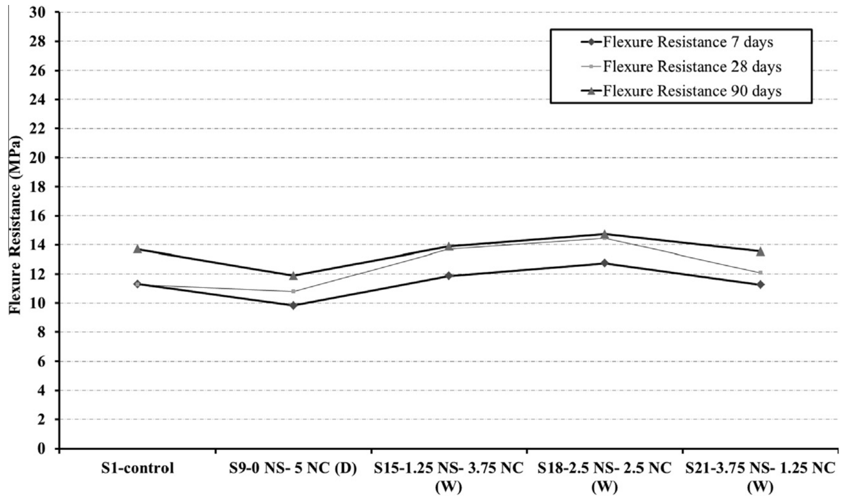


**Fig. 18** Effect of 5 % hybrid Nano particles on flexure strength.

generate more strength and to reduce free calcium hydroxide. A similar trend was observed in flexure strength as shown in Fig. 14.

3% Hybrid nano with mix of 25% NS and 75% NC improves the compressive strength with 25% for 7 days, 56.5% for 28 days and 29.1% for 90 days than control mix. Also improves the compressive strength with 21.6% for 7 days, 6.4% for 28 days and 16.8% for 90 days than 3% nano clay mix as shown in Fig. 15. This improvement can be referred to the filler action of nano silica and nano clay and suitable mix percentage, also reacts with calcium hydroxide which increases calcium silicate hydrate (C.S.H.) which reflects on the interface structure. A similar trend was observed in flexure strength as shown in Fig. 16.

5% Hybrid nano with mix of 25% NS and 75% NC improves the compressive strength with 8.7% at 7 days,19.8% at 28 days and 15.6% at 90 days than control mix. Also improves the compressive strength with 2.5% for 7 days, 4.6% for 28 days and 16.7% for 90 days than 5% nano clay mix as shown in Fig. 17. This improvement can be referred to filler action of nano silica and nano clay, since nano silica consumes a more part of calcium hydroxide. Also at 5% hybrid mix with 75% NS and 25% NC the improvement of compressive strength was about 5% at 90 day and 14% at 7 and 28 days of those of the same percentage of nano Hybrid 25% NS and 75% NC. It means for more economic and effective results 25% NS and 75% NC is suitable for improvement of the strength. This increase in the compressive strength of hybrid mix 75% NS and 25% NC is attributed to the high percentage of nano silica up to 3.75% as a replacement of cement which fills and reacts with the cementations materials (cement and silica fume).

As shown in Fig. 18, 5% Hybrid nano with mix of 25% NS and 75% NC improves the flexure strength with 5% for 7 days, 21.8% for 28 days and 1.3% for 90 days than control mix. Also improves the flexure resistance with 20.9% for 7 days, 26.7% for 28 days and 16.7% for 90 days than 5% nano clay dry mix. This improvement can be referred to filler action of nano silica and nano clay, since nano silica consumes a more part of calcium hydroxide which enhances the C.S.H structure. Also at 5% hybrid mix with 50% NS and 50% NC had improvement of flexure resistance was about 6.1% at 90 day, 7.4% at 7 days and 5.5% at 28 days of those of the same percentage of nano Hybrid 25% NS and 75% NC. It means for more economic and effective results 25% NS and 75% NC is suitable for improvement of the strength. This increase in the flexure strength of the hybrid mix of 50% NS and 50% NC is due to the high percentage of nano silica up to 2.5% as a replacement of cement which fills and improves the crack distribution due to increase in calcium silicate hydrate.

It can be concluded that at constant percentage of the nano particles and at the same mixing condition, the hybrid nano particles improve the compressive and flexure strengths than using each type of nano materials separately.

The effect of using wet mixing in addition of nano clay in comparison with dry mixing on the compressive strength is presented in Fig. 19, which indicated the effect of adding 1% dosage of nano clay in dry and wet condition. It increases the compressive strength more than the control mix with 1.25 and 17.9 for 7 days, 11.9 and 25 for 28 days, −0.48 and 23.3 for 90 days, respectively. Also increases the compressive strength of wet mix about 16.4%, 11.7% and 23.9% than dry mix at 7, 28 and 90 days respectively, this increase in compressive strength refers to proper conditions for chemical reaction also as a good and uniform dispersion of nano particles at wet mixing. A similar trend was observed in flexure resistance as shown in Fig. 20.

Also the effect of using wet mixing in the case of addition of hybrid nano particles than dry method on the compressive strength is presented in Figs. 21–23 for 1%, 3% and 5% replacement of cement, respectively, which indicated; at high percentage of nano particles the difference between the wet and dry conditions appears strongly at 90 days. Fig. 21 shows an improvement in compressive strength of wet mixing 1% hybrid by about 19.1% and 5.7% than control and dry mix, respectively.

Fig. 22 shows an improvement in compressive strength of wet mixing 3% hybrid nano about 17.8% and 1.4% than control and dry mix, respectively at 90 days.

Fig. 23 shows an improvement in compressive strength of wet mixing 5% hybrid nano about 17% and 5.9% than control and dry mix, respectively at 90 days.

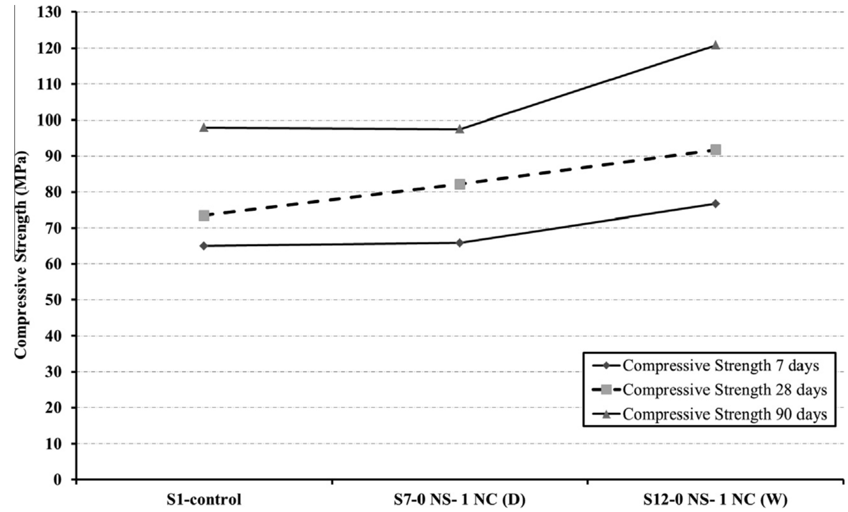


**Fig. 19** Effect of mixing condition for NC on compressive strength.

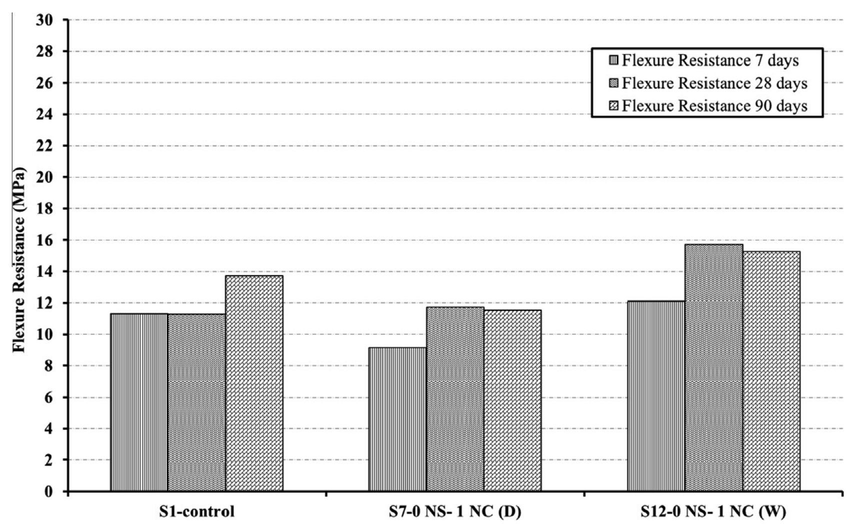


**Fig. 20** Effect of mixing condition for NC on Flexure Resistance.

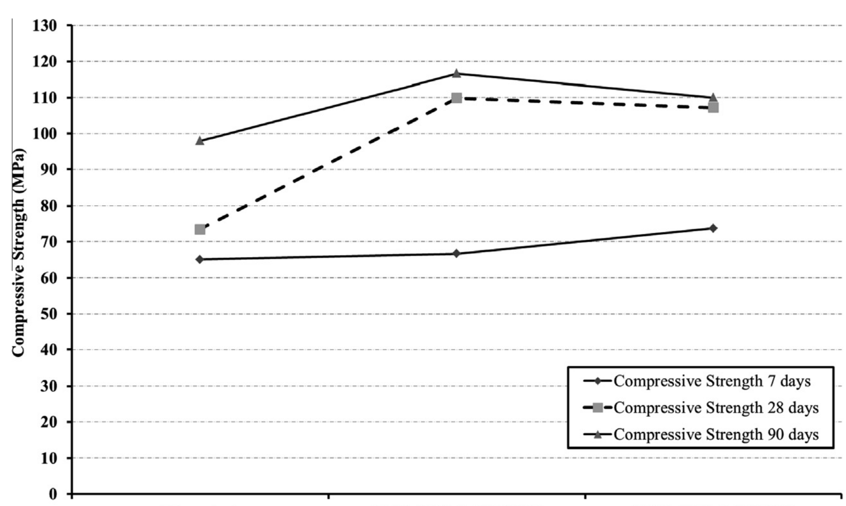


**Fig. 21** Effect of mixing condition for 1% hybrid Nano on compressive strength.

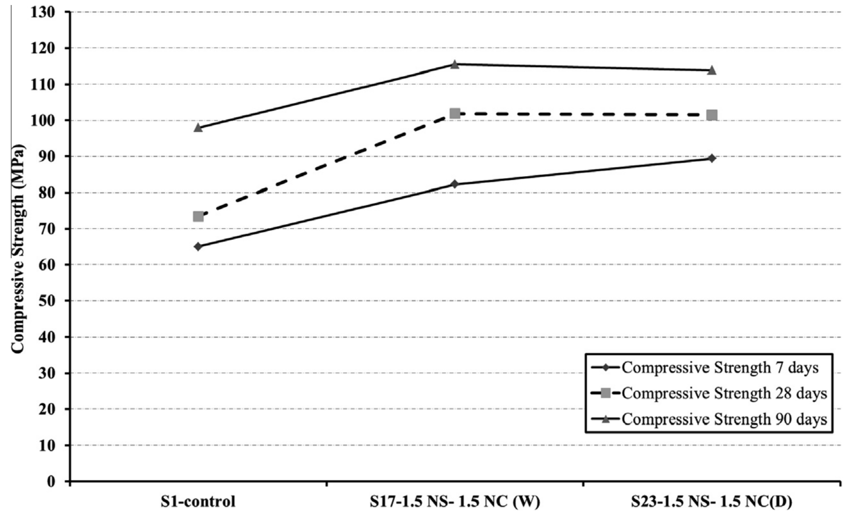


**Fig. 22** Effect of mixing condition for 3% hybrid Nano on compressive strength.

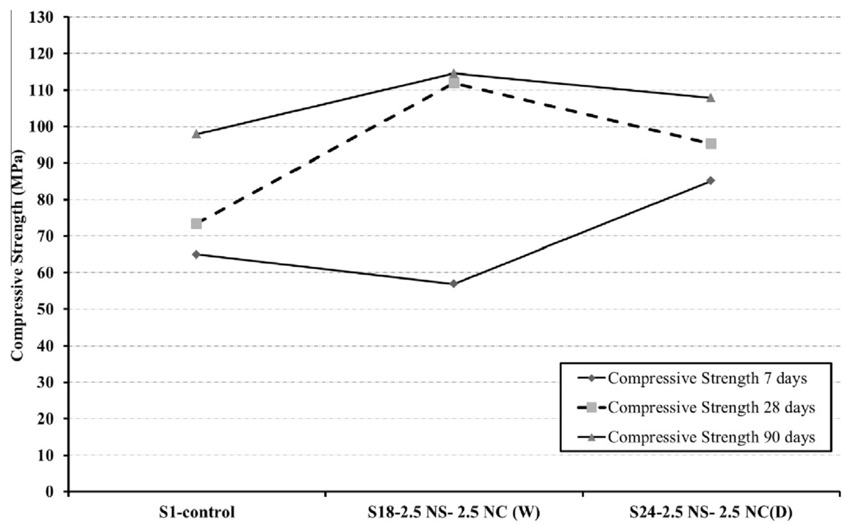


**Fig. 23** Effect of mixing condition for 5% hybrid Nano on compressive strength.

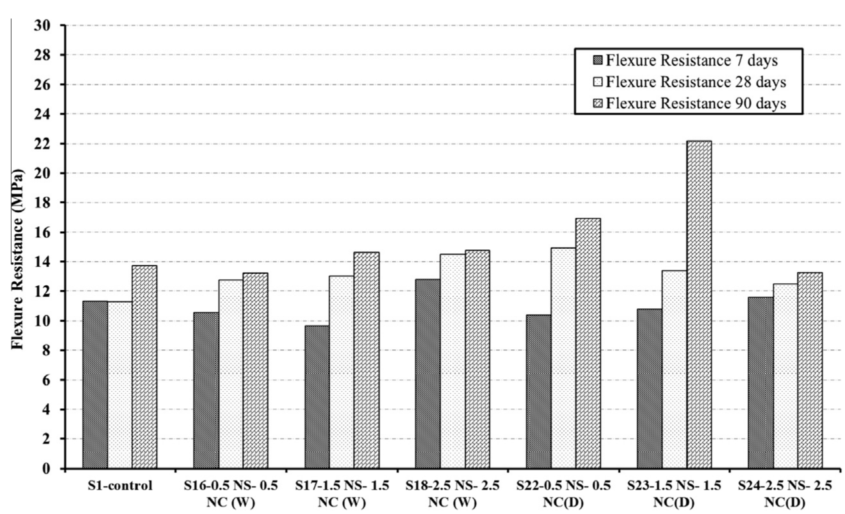


**Fig. 24** Effect of mixing condition for 1%, 3% and 5% hybrid nano on flexure resistance.

Effect of using wet mixing in addition to hybrid nano particles than the dry method on the Flexure resistance at 7, 28 and 90 days is presented in Fig. 24 for 1%, 3% and 5% as a replacement of cement with 50% NS and 50% NC, which indicated increase in flexure strength in dry condition than wet mixing especially at 90 days with 1% and 3% hybrid nano particles. This improvement in flexure resistance in dry condition is due to increase in the bond between the aggregate and the cement matrix and this bond is the most effective factor in increasing the flexure resistance of the cement mortar. Nano-particles improved the quality of the interfacial zone due to the precipitation of smaller and stronger C- S-H gel and the accelerated rate of hydration. Otherwise at 5% nano particle replacement, the flexure strength decreases due to over dosage of nano particles which may cause agglomeration of nano particles and reflects to the bond between aggregate and cement paste.

## Conclusions

1- Nano Silica in wet condition and nano Clay in dry condition have remarkable improvement on the compressive strength of high performance concrete till 18% days enhancement for nano silica and 11% enhancement for nano clay at 90 days, due to the reaction of nano materials with calcium hydroxide $Ca(OH)_2$ crystals, which are arrayed in the interfacial zone (ITZ) between hardened cement paste and aggregates, and produce C-S-H gel and the filling action of nano particles which cause more densified micro structure.
2- An improvement for flexure strength due to use of nano particles can be achieved till 4% and 8% at 90 days for NS and NC respectively, due to the filler action of nano particles which increases the bond between the aggregate and the cement matrix.
3- The optimum percentage for replacement of cement with nano particles which was 0.75% for NS and 3% for NC in this study and additional percentage may reflect negatively on the compressive and flexure strength of concrete due to agglomeration of nano particles, also to achieve economical mix since increasing the cost of mix without major effect on the mechanical properties is noticed.
4- The wet mix for nano clay is more efficient than dry mix with approximately 24% and 32% improvement in compressive and flexure strength, respectively at 90 days due to the good uniform dispersion of the nano particles in concrete mix and suitable reaction conditions.
5- The hybrid nano particles had a remarkable improvement on the compressive strength of high performance concrete than the same percentage of the nano particles used separately. This improvement can be referred to the filler action of nano silica and nano clay and proper mix percentage. The optimum Hybrid ratio in this study can be noticed with 3% nano particles consists of 25% NS and 75% NC which can easily be produced in Egypt and which gives best results in both compressive and flexure strength, in addition this percentage is nearly the same of the optimum percentage of each nano type used alone.
6- The wet mix hybrid nano particles are more efficient than dry mix hybrid with approximately 6% improvement in compressive strength at 90 days due to the good uniform dispersion of the nano particles in concrete mix.
7- The dry mix hybrid nano particles are more efficient than wet mix hybrid with approximately 28% and 52% improvement in flexure resistance at 90 days for 1% and 3% hybrid nano particles respectively, due to the increase in the bond between aggregate and cement paste. Nano-particles improved the quality of the interfacial transition zone due to the precipitation of stronger C- S-H and the accelerated rate of hydration.

## Conflict of interest

None.

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